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WILDFIRE EFFECTS ON PLANT AND ANIMAL COMMUNITIES IN ARIZONA PONDEROSA PINE FORESTS

E. Lee Fitzhugh

THESIS
AND
REPORTS

WILDFIRE EFFECTS
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IN ARIZONA PONDEROSA PINE FORESTS

By

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ABSTRACT

Plant species composition and use by deer, elk, and cattle were monitored after a 748 acre early spring wildfire which burned in the ponderosa pine type on limestone-derived soils southwest of Flagstaff, Arizona. Plants which increased or decreased after either severe or moderate intensities of fire were identified. The moderately burned area was similar in species composition to the control (unburned) areas after three growing seasons, but remained much higher in herbage production. The severely burned area showed signs of continued plant succession after three growing seasons. During the year of the fire there was no detectable difference in herbage production between any of the areas, illustrating rapid recovery of the burned areas. After the third growing season the severely burned area produced more than the moderately burned area, and both produced much more than the controls. Use of the areas by elk and cattle either could not be tested or differences could be explained by factors unrelated to the fire. Use by deer of the severely burned area exceeded the level of the control after two years. Use by deer of the moderately burned area exceeded that of the control the year of the fire. Use by deer of the severely burned area appears to be increasing, while use of the control and, to a lesser extent, the moderately burned area is decreasing. The pattern of use by deer in

different years and on different areas appears to be related to the production of highly palatable plants. more than to total herbage production. The fire appeared to be immediately beneficial to deer in moderately burned areas and beneficial after two years in severely burned areas. There was little detrimental effect on deer, elk, or cattle use of any of the burned areas.

INTRODUCTION

Fire has been considered as a tool in managing ponderosa pine forests to reduce potential fuel for wildfire and improve the production of timber, wildlife, and beef. Increasing demands for these products indicate that the use of controlled fire and the treatment of areas burned by wildfire will become increasingly necessary. In order to prescribe treatments for burning and for areas burned by wildfire, information is needed concerning the nature of fire-caused changes in the plant and animal resources on specific soil-plant communities.

The objective of this study was to determine the changes in a plant community and the use pattern of large herbivores as a result of different intensities of wildfire on a limestone-derived soil in a moist ponderosa pine type southwest of Flagstaff, Arizona.

This study was initiated with funds from Northern Arizona University, and completed with funds from Eisenhower Consortium cooperative agreement 16-454-CA. In addition, the authors gratefully acknowledge assistance and advice from various personnel of the Rocky Mountain Forest and Range Experiment Station, Flagstaff and Tempe, Arizona, and Fort Collins, Colorado. The U. S. Forest Service made

available the area of the Rattle Burn and various data they collected there. Personnel of the Arizona Game and Fish Department also provided advice and assistance. Dr. W. B. McDougall of the Museum of Northern Arizona identified voucher specimens of most of the forbs mentioned in this report.

LITERATURE REVIEW

A few papers have been written about the historical and general place of fire in ponderosa pine vegetation (Biswell, 1967, and Weaver, 1967, for example). A number of papers have been written about specific effects of fire on one process or another. Those effects which have a direct bearing on plant succession or wildlife use of a burned area will be briefly reviewed.

Effect of Fire on Soil Factors

Zwolinski (1966) studied the effects of fire on water infiltration capacity under ponderosa pine forest. De Bano and Rice (1973), Tarrant (1956), Fuller, Shannon, and Burgess (1955), and Davis, Ffolliott and Clary (1968) have studied the effect of fire on soils under ponderosa pine forests. Of particular interest is the formation of a water repellent layer under the soil surface caused by the deposition of a chemical coating on soil particles under certain fire conditions. An increase in some available soil nutrients also occurs as a result of fire. Clary, Ffolliott, and Jameson (1968) found that the humus layer accounted for more change in herbage production than did the litter or duff layers in a volcanic soil in northern Arizona pine forest.

Effect of Fire on Plant Reproduction

Methods of survival for understory vegetation in fire regimes include sprouting, seed polymorphism, dormancy, and airborne invasion. Quercus and Robinia are two good examples of genera that sprout after a fire (Sweeney, 1967). Sprouting rejuvenates the plant and provides a good source of food for browsing animals. Chenopodium displays a useful seed polymorphism (Williams, 1962). Approximately 30 percent of the seeds germinate readily, the others need heat scarification. This adaptive mechanism makes possible the presence of the plant in the intervals between fires and accounts for their sharp increase following fires. Ceanothus seeds are noted for their ability to lie dormant in litter for years and germinate rapidly following a fire (Quick, 1959). Senecio, Epilobium, and Cirsium, which have tiny airborne seeds are rapid invaders on disturbed soil surfaces (Hooven, 1973).

Persistence of Fire-causes Effects

Hooven (1973), working in the Pacific Northwest, mentioned that it takes several years following logging or fire for plant life to respond with new diversity. Reynolds (1962), working in northern Arizona, indicated that it

takes six years after logging for the diversity in vegetation to maximize, and another nine years for the former species to reestablish themselves.

The Effect of Fire on Plants

Ahlgren and Ahlgren (1960) wrote a good comprehensive review of the effects of forest fires in terms of basic principles, but their paper has little direct application for ponderosa pine in Arizona. Hooven (1973), in discussing clearcuts and fires in the Pacific Northwest Douglas-fir region, mentioned that the type and intensity of disturbance exerted a large influence on vegetational succession. Regardless of the type of disturbance, one result was a significant increase in plant species in the Douglas-fir region.

Pearson, Davis, and Schubert (1972) discussed the effects of a 350-acre wildfire on grasses and forbs in a northern Arizona ponderosa pine forest. The fire they studied was on basalt-derived soils and occurred in May. The condition of the forest was such that the fire was naturally divided into a severely burned area (crown fire) in an unthinned stand and a moderately burned area (ground fire with tree scorch several meters high) in a thinned

stand. The researchers found that burning initially stimulated growth of native herbaceous vegetation in both stands. Production on the unthinned, severely burned area the first year was 63 pounds per acre. Production on the thinned, moderately burned area was 769 pounds per acre. An unthinned, severely burned area seeded after the fire produced 53 pounds per acre the first year and 1023 pounds per acre the next year. A large increase in Ceanothus fendleri was noted in the burned areas. In the unthinned, severely burned area, both native grasses and forbs increased, while forbs increased at the expense of native grasses in the thinned, moderately burned area. Pearson, et al.,(1972) also found an increase in digestibility, crude protein, and phosphorus content of the plants. Komarek (1967) and Lay (1956) have noted similar changes in nutrient content after fire.

Effect of Fire on Wildlife

Kruse (1972), as a part of the same study reported by Pearson, et al. (1972), indicated that the fire improved deer and elk habitat. He related the use by deer and elk to forage production on seeded and unseeded areas in the burn.

Other studies of wildlife and fire in ponderosa pine are more general in nature. Weaver (1958) limits himself to a subjective evaluation of the effect of burning on range and forage values in Washington and Oregon. Davis et al. (1968) have only a short paragraph about herbaceous and shrub productivity.

Even though little research is available specifically about the effect of fire in ponderosa pine on changes in wildlife habitat, information is available from which inference can be made. For example, Reynolds (1966) has shown that in northeastern Arizona, elk and cattle used openings more heavily than forested areas, but deer used forests and openings almost equally. Reynolds' data appear to indicate that both deer and elk use of openings decreases at about 600 feet from the forest border.

It has also been shown that the amount of understory in a forested area is inversely proportional to the amount of overstory (McConnell and Smith, 1970), thus affecting food availability. On volcanic soils in northern Arizona, herbaceous production in an unthinned ponderosa pine forest varied from 119 pounds per acre at 120 square feet of tree basal area to 377 pounds at 20 square feet of basal area (Clary and Ffolliott, 1966).

In another study in northern Arizona, elk use was higher with higher total forage production. Long-term deer use was random, but annual use appeared to vary, perhaps with food availability or habitat changes (Clary and Larson, 1971). Clary and Larson found no significant relationships between deer use and herbage variables or between elk use and acorn, dwarf mistletoe, or grass production. In contrast, Reynolds (1966) found that the density of fecal groups varied with the type of herbaceous cover. He found more elk groups on grassy areas and more deer groups on forb-rich areas. Data in Patton (1969) tends to support Reynolds' conclusions. Both Patton and Reynolds worked in eastern Arizona, while Clary and Larson worked in northern Arizona.

From this review, we may conclude that many wildfires are likely to be good for deer habitat. At least one specific study in northern Arizona has so stated, and has related the benefit to increased forage production, digestibility, and nutrient content. Fire may be expected to reduce timber density and thus increase herbage production. The creation of openings may be assumed to benefit elk and cattle, if not deer, as long as the openings are not too large. The effects of fire may vary, however. Different intensities of fire may cause water repellent

layers to develop in the soil, restricting herbaceous recovery and food production. Fire intensity may affect successional stages, the relationship of grasses to forbs, and the quality of the forage thus produced. The size of openings created by intense wildfire may be restrictive to some wildlife. As Hooven (1973) indicated, alterations will benefit certain species at the expense of others. Thus the manager needs information of a specific nature rather than of a general nature, in order to make accurate predictions and prescriptions.

In summary, no one has put in quantitative terms in one study the changes in animal and plant life that take place in ponderosa pine forests as a result of wildfire. Rarely has anyone detailed the changes among herbaceous and shrubby plants as a result of fire, in comparison with an adjacent unburned area. As a result, it is difficult for an administrator to predict the ecological effects of fire in ponderosa pine on animals and understory plants except in general terms.

STUDY AREA

On May 7-9, 1972 the Rattle Fire burned 748 acres, 18 miles southwest of Flagstaff, Arizona (Schinzel and Meurisse, 1972) after a prolonged dry period. The burned area is a long oval shape (Figure 1). There are areas on the north sides of small hills which were "moderately burned" (Herman, 1954, class 1) by ground fire, with patches of dense tree reproduction also burning. Other moderately burned areas were larger, coinciding with the occurrence of nighttime conditions and areas purposely burned to stop the wildfire. These larger moderately burned areas occur at the northern end of the burn and on the east side. The southern end of the burn, where the fire began, was "severely burned" (Herman, 1954, class 3) by a high-intensity ground and crown fire which consumed most of the soil organic matter and destroyed most plant life (Table 1). A canyon dissects the southern end of the burn and continues through the moderately burned portion on the east side.

Description of the Area

The Rattle Burn is in a Pinus ponderosa- Muhlenbergia virescens- Quercus gambelii community, although at the

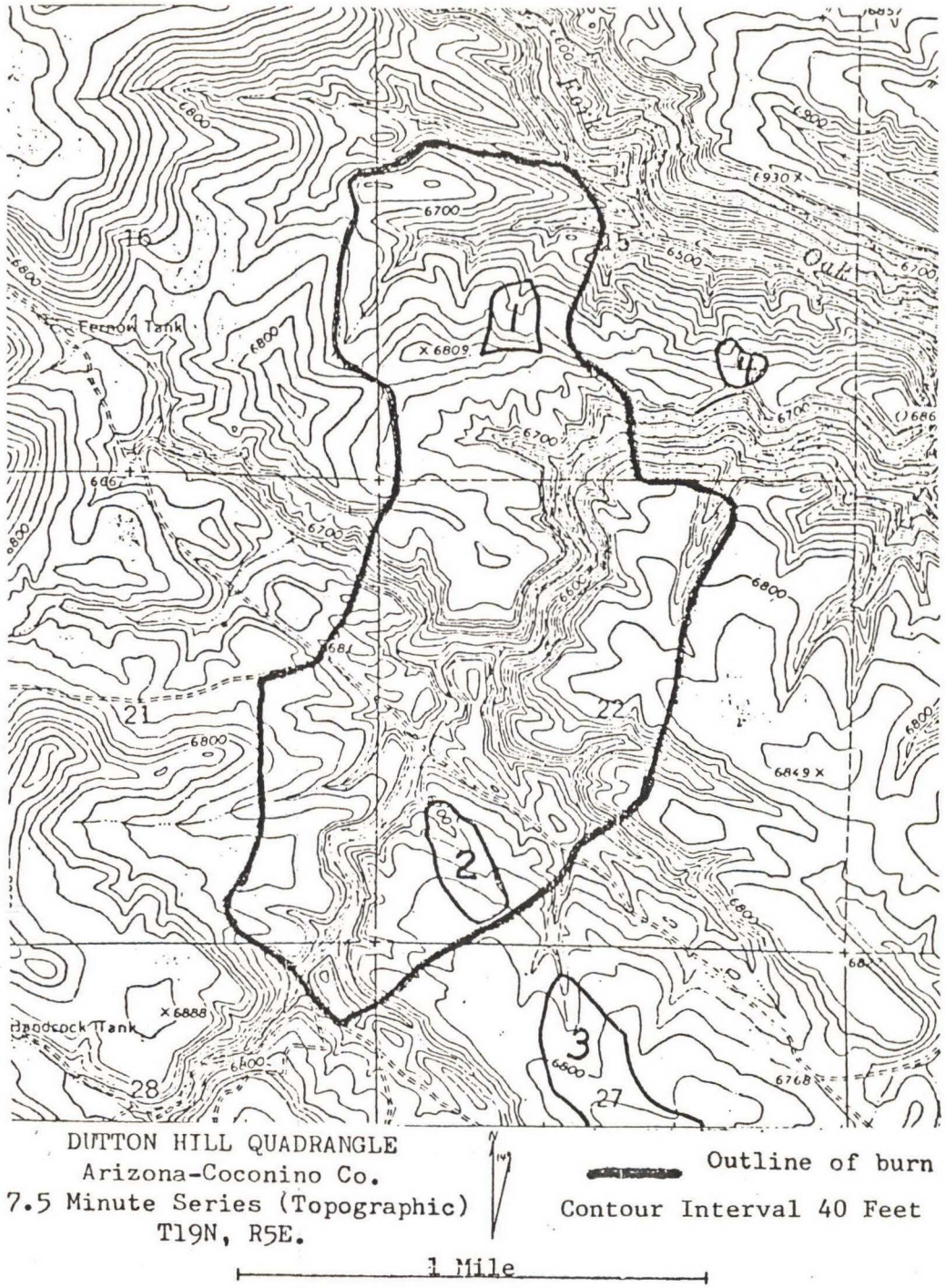

Figure 1. Map of the Rattle Burn, 18 miles southwest of Flagstaff, Arizona, showing the locations of watersheds studied.

Table 1. Results of a timber inventory, showing the effect of the Rattle wildfire on ponderosa pine.[1]

Quantity measured[2]	Unburned	Moderately burned	Severely[3] burned
Trees per acre before fire	367	431	412
Trees per acre after fire	367	156	28
Basal area, sq. ft./acre before fire	121	133	129
Basal area, sq. ft./acre after fire	121	103	40
Cords per acre before fire	6.9	8.0	8.2
Cords per acre after fire	6.9	4.9	0.8

1) From "An overstory inventory of watershed RB 1, 2, 3." (unpublished), Rocky Mountain Forest and Range Experiment Station, Flagstaff
2) Based on trees alive at the time represented.
3) Most of the trees after the fire were grouped at the upper boundary of the watershed.

south end there are irregular areas with minimal amounts of Quercus gambelii (Hanks and Fitzhugh, 1975).

The timber site indices range from 65 to 136, with 42 trees giving an average site index of 89.6. There is little variation in site index from one end of the burn to the other (from "An overstory inventory of RB 1, 2, 3.", an unpublished report on file at the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona).

Soils are in the Soldier, Hogg, and McVickers series, fine sandy loams derived from limestone with varying degrees of stoniness and rockiness (Schinzel and Meurisse, 1972).

Precipitation was recorded by the U. S. Forest Service and is presented in Table 2. Temperatures were also recorded, with the average annual temperature about 45°F. The lowest average monthly minimum recorded was 8° in January, 1975, the only January on record. The lowest recorded average monthly minimum during the period of the study was 13° in December, 1973. The average monthly maximum was very near 84° each year, in June or July.

Table 2. Total precipitation by winter and summer periods for Rattle Burn, southwest of Flagstaff, Arizona.[1]

Water Year	Precipitation in Inches	
	October-April	May-September
August 1972-Sept. 1972[2]	Not recorded	2.21[2]
Oct. 1972-Sept. 1973	18.47	6.01
Oct. 1973-Sept. 1974	6.19	4.65

1) From a recording rain gauge in the severely burned area at the south end of the burn. Unpublished data, U.S. Forest Service, Rocky Mountain Forest and Range Experiment Station, Flagstaff.
2) Rain gauges were installed in August, 1972. Precipitation from May to August 1972 consisted of light rains spaced at approximately two-week intervals, near-optimum for plant growth and unusual for the area.

Logging Activities Before and After the Fire

A "light" timber harvest took place in the spring of 1970, the results of which are presented in Tables 3 and 4. Prior to that, there is evidence of high-grade logging about 1900, as judged by the condition of the stumps. After the 1970 harvest, skid trails were planted with a mixture of two pounds of Festuca ovina per acre, and one pound each of Dactylis glomerata, Bromus inermis, Phleum pratense, and Sanguisorba spp. (Personal communication, Frank Daniels, Range Conservationist, Flagstaff Ranger District, Coconino National Forest, Flagstaff, Arizona).

After the fire approximately 1,850,000 board feet (2,473 board feet per acre) were removed in a salvage operation during the summer and fall of 1972 and spring of 1973 (U.S.Forest Service timber sale records, Flagstaff Ranger District). Removals from the areas studied and the amounts remaining are in Tables 5 and 6. Skid trails were seeded after the salvage operation at 10 pounds per acre, with one part of each of the following: Dactylis glomerata, Bromus inermis, Festuca ovina, Agropyron smithii, Elymus juncus, and Melilotus officinalis (Personal communication, Frank Daniels).

Table 3. Removals by timber harvest in 1970 from the areas studied in and near Rattle Burn.[1]

Quantity measured	Amount removed in each area		
	Unburned	Moderately burned	Severely burned
Basal area, square ft. per acre	90	61	61
Cubic feet per acre	3271	2059	1836
Board feet per acre	17668	11262	9754

Table 4. Amount of timber left after harvest in 1970 from the areas studied in and near Rattle Burn.[1]

Quantity measured	Amount left after harvest		
	Unburned	Moderately burned	Severely burned
Basal area, square ft. per acre	121	133	129
Cubic feet per acre	2944	2714	3067
Board feet per acre	11665	8962	11138

Table 5. Removals by timber salvage in 1972 from the areas studied in and near Rattle Burn.[1]

Quantity measured	Amount removed in each area		
	Unburned	Moderately burned	Severely burned
Basal area, square ft. per acre	none	60	122
Cubic feet per acre	none	1055	2873
Board feet per acre	none	2430	10355

Table 6. Amount of timber left after timber salvage in 1972 from the areas studied in and near Rattle Burn.[1]

Quantity measured	Amount left after harvest		
	Unburned	Moderately burned	Severely burned
Basal area, square ft. per acre	121	73	7
Cubic feet per acre	2944	1658	194
Board feet per acre	11665	6532	784

1) From "An overstory inventory of watershed RB 1, 2, 3." (unpublished), Rocky Mountain Forest and Range Experiment Station, Flagstaff.

During the summer of 1973 the areas south and east of the burn, including the control area near the severely burned portion, was "lightly thinned". No figures are available to quantify the thinning. In the burned area, cleanup operations with heavy equipment also continued during the summer of 1973 and caused disturbance to soil, vegetation, and pellet plots in the burned study areas.

Grazing Activities Before and After the Fire

An inspection of records reveals that the Rattle Burn area has historically been overgrazed (U. S. Forest Service grazing allotment records, Coconino National Forest). The burn includes parts of two Forest Service grazing allotments, the Barney Pasture allotment in the south part of the burn, and the Lockwood Spring pasture of the Rogers Lake allotment in the northern portion of the burn. Both the Barney Pasture allotment and the Lockwood Spring pasture extend far beyond the boundaries of the burn. The permitted number of cattle amount to an average of 23 acres per animal unit month (AUM) in the Lockwood Spring pasture, and 44 acres per AUM in the Barney Pasture areas. However, in 1974 the Barney Pasture allotment experienced water distribution problems, and an additional 50 head of cows grazed in the vicinity of the burn instead of elsewhere in the allotment as is normal (Personal communication, Frank Daniels).

Other Research on the Area

This study was designed in conjunction with watershed studies conducted by the Rocky Mountain Forest and Range Experiment Station, Flagstaff. The study areas from which vegetative information was obtained are the same as the experimental watersheds. The locations of watersheds are shown in Figure 1. Vegetative plots in this study occur within square, tenth-acre timber inventory plots which gave the results in Tables 1, and 3-6. Watershed aspects of the study are not treated in this report, but the term "watershed" will be retained to facilitate comparison of these results with results of the watershed studies which will probably be published at a later date. In addition, the term "watershed" will facilitate differentiation between the vegetative studies on the watersheds and the herbivorous animal studies which covered study areas much larger than the watersheds.

Rodent populations on the area were monitored. A manuscript on the results is in preparation by P. O. Lowe, P. F. Ffolliott, E. L. Fitzhugh, and W. P. Clary.

METHODS

Choice of Vegetative Study Areas

Vegetation study areas were initially chosen by personnel of the Rocky Mountain Forest and Range Experiment Station, after field inspection and consultation with the senior author. Criteria for location of the study areas were two: 1) location of a suitable weir site for a 10 to 20 acre watershed; 2) conditions on the watersheds representative of the moderately, severely (classes 1 and 3 of Herman, 1954), and unburned situations; 3) similar to each other in aspect, topography, soils, and pre-fire vegetation. The locations of watersheds thus chosen are shown in Figure 1.

Once a watershed was chosen, 90 vegetative plots, 9.6 square feet each, were systematically located in clusters of three around "sampling points". Figures 2, 3, and 4 show sampling points on each of the three watersheds. Figure 5 represents the vegetative plot location around a sampling point and within a timber inventory plot.

After field work in 1972, the senior author became

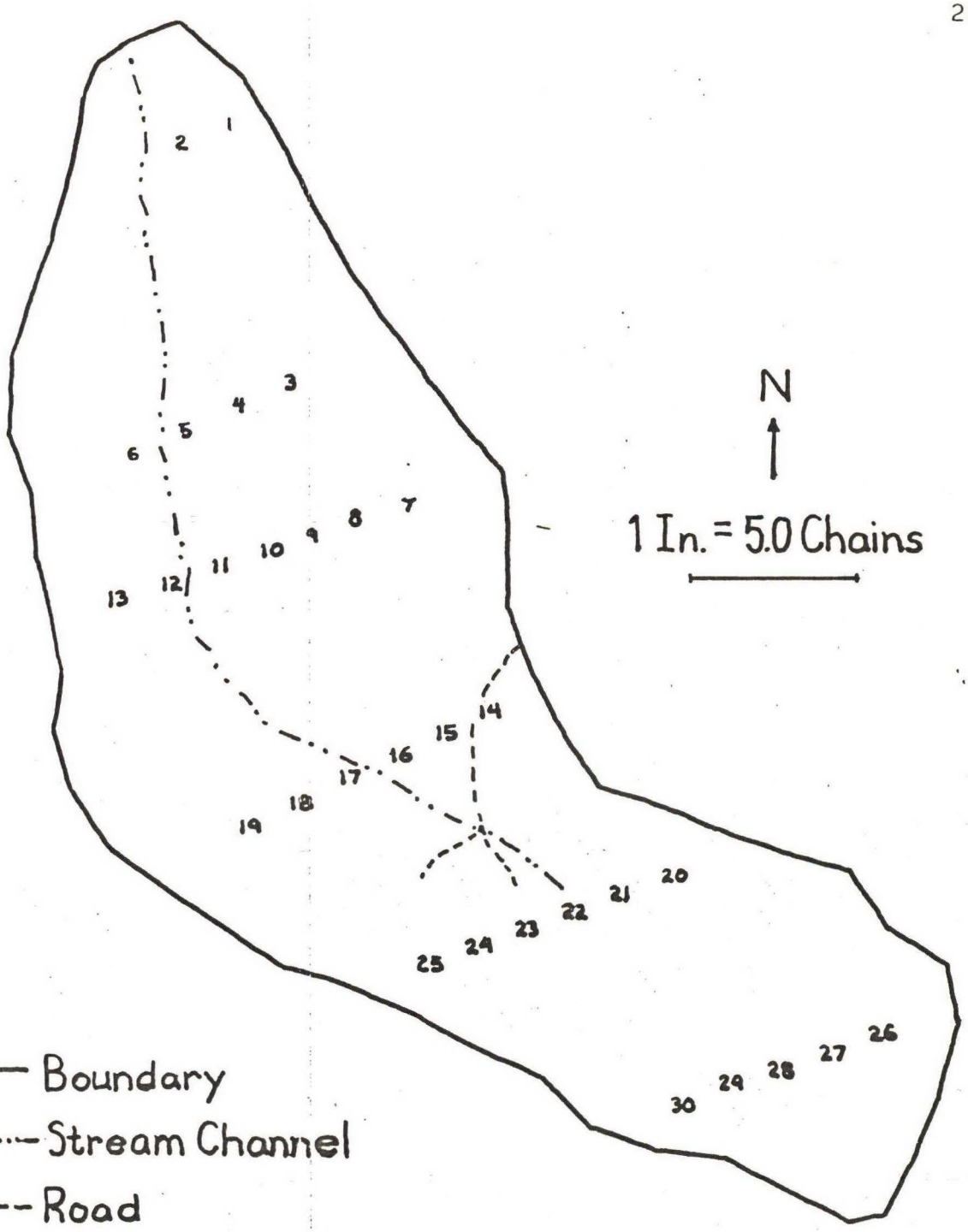

Figure 2. The location of sampling points in the unburned watershed (south control), Rattle Burn.

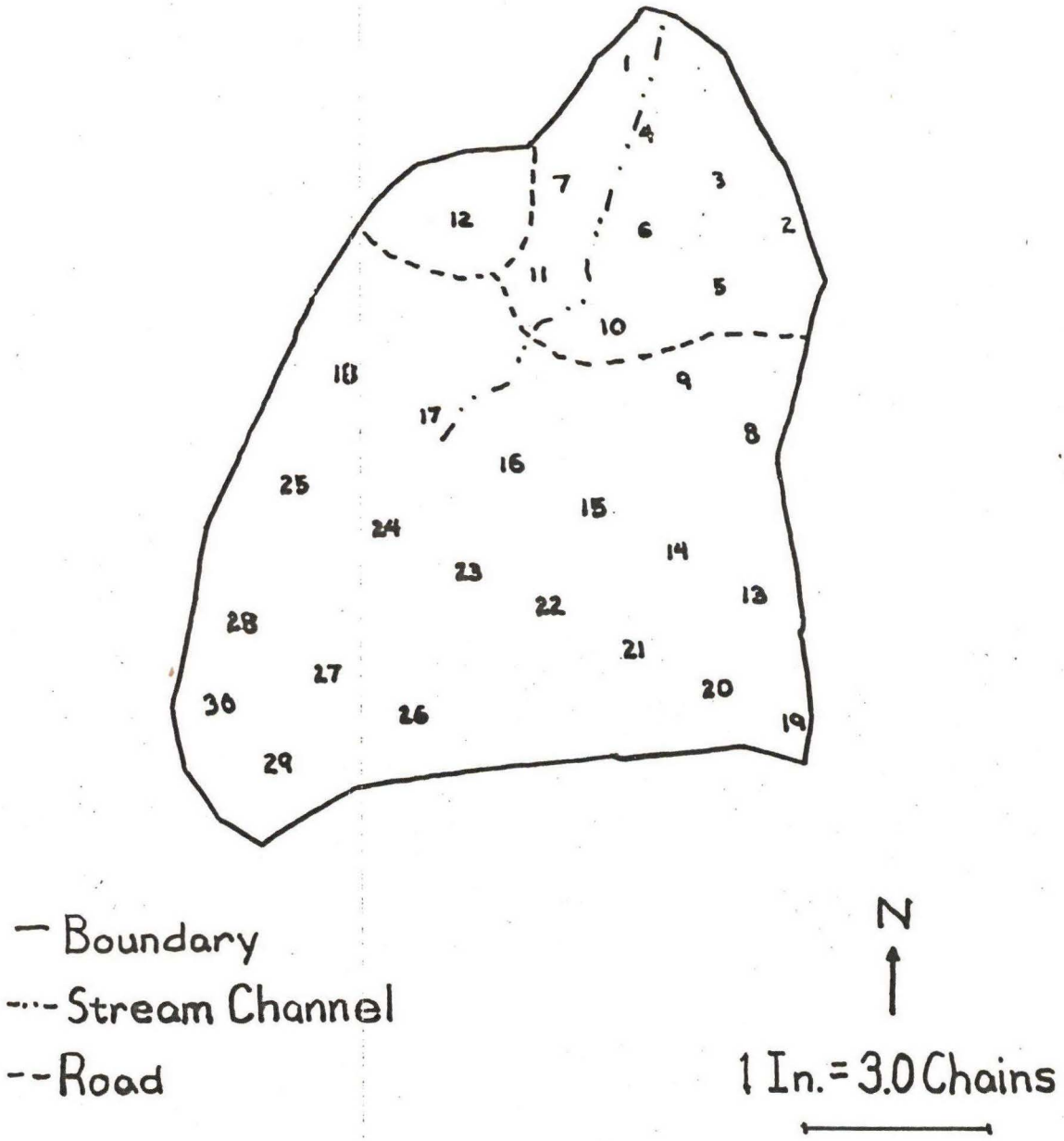

Figure 3. The location of sampling points in the moderately burned watershed, Rattle Burn.

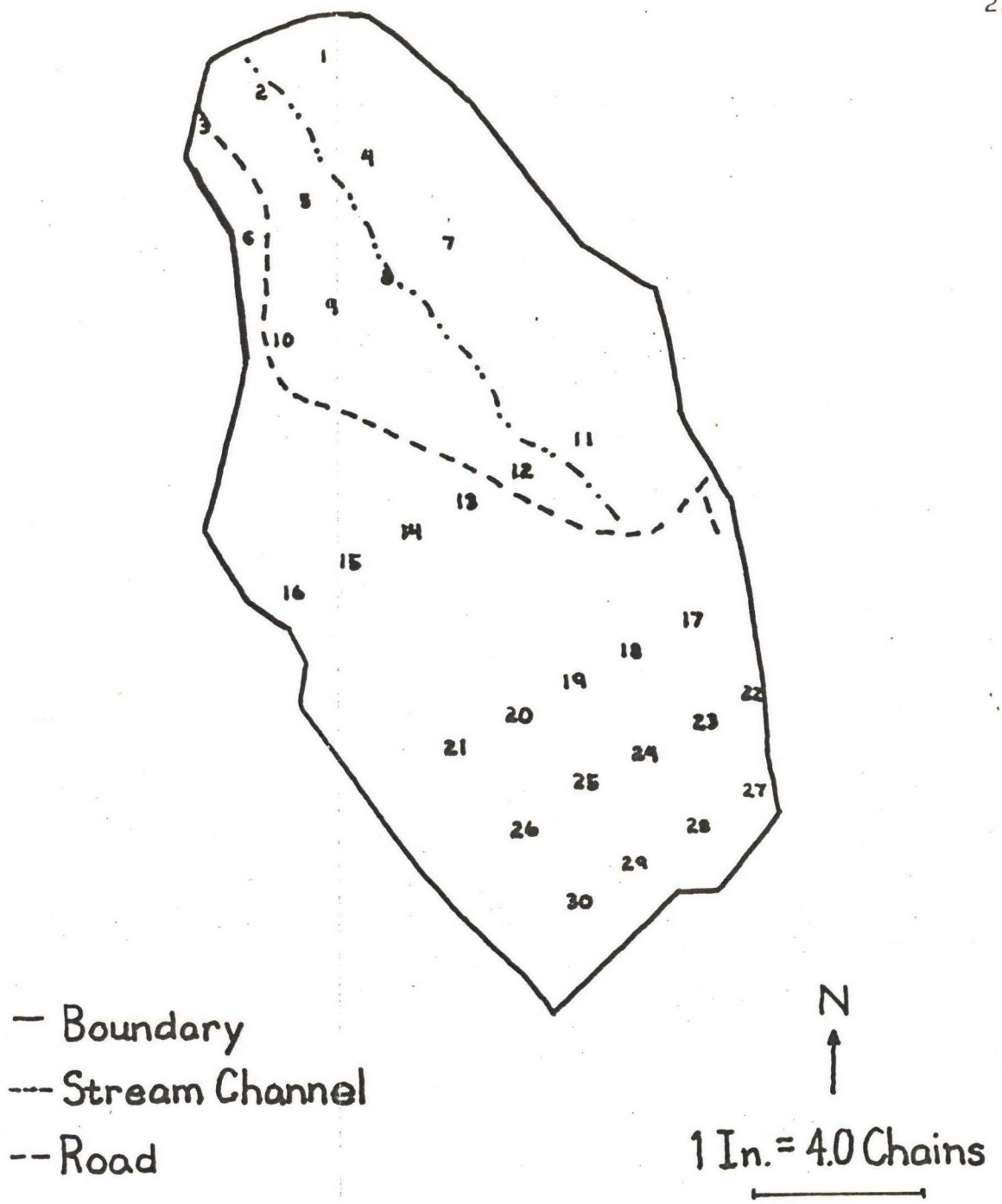

Figure 4. The location of sampling points in the severely burned watershed, Rattle Burn.

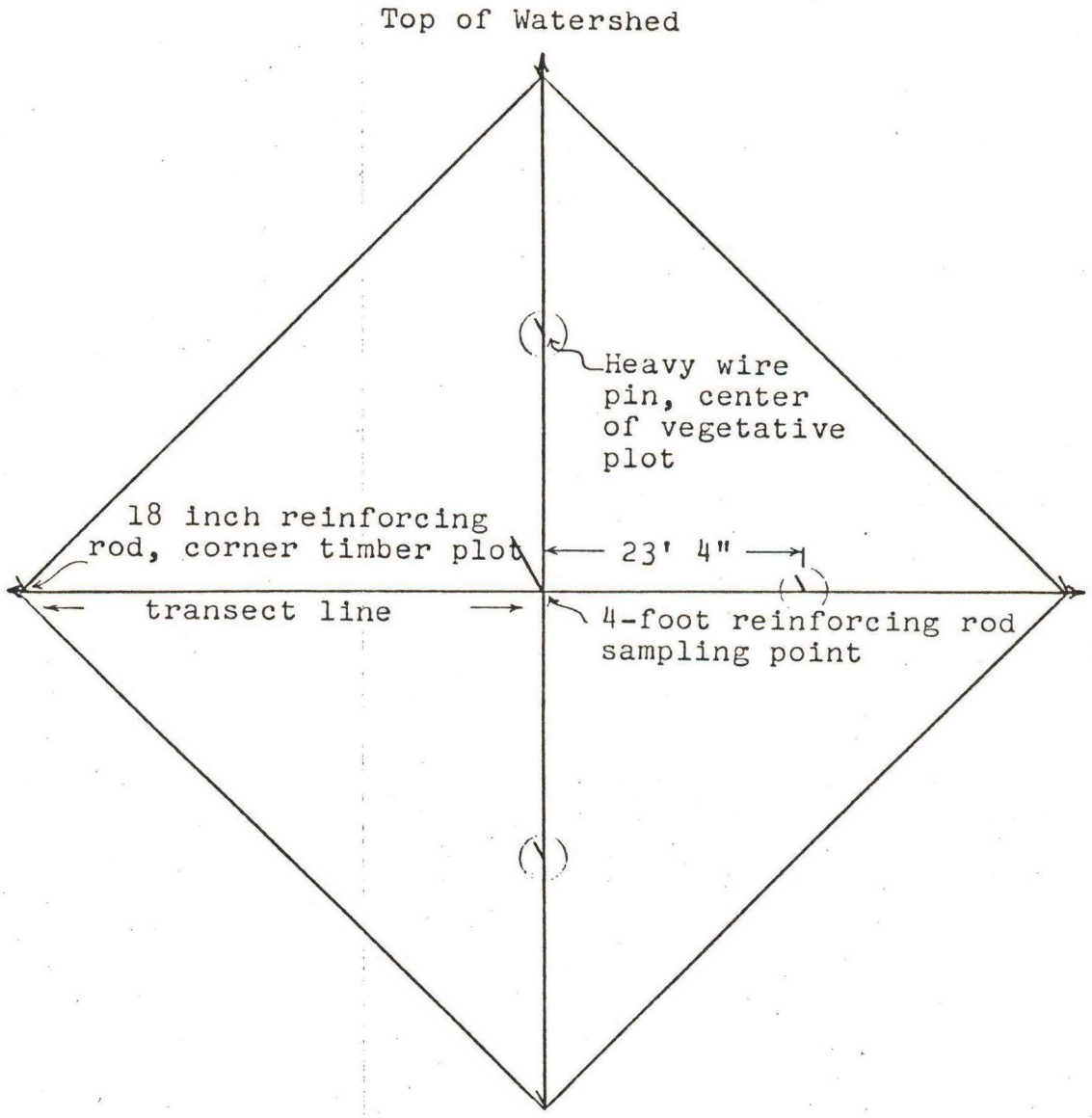
Top of Watershed
Heavy wire pin, center of vegetative plot
18 inch reinforcing rod, corner timber plot
23' 4"
transect line
4-foot reinforcing rod sampling point

Figure 5. The location of vegetative plots around sampling points and within timber inventory plots, Rattle Burn

concerned about differences in vegetation between the control area near the south end of the burn and unburned areas at the north end of Rattle Burn. Therefore, when field work began in 1974, a new control area was established at the north end of the burn to test the validity of the control area used in 1972. Criteria for location of the north control area were as nearly as possible the same as for the original watersheds. Figure 6 represents the location of sampling points in the north control area. The control area established in 1972 will hereafter be designated the "south control" area.

Vegetative Measurement Techniques

In mid-August of 1972 and 1974, all stems of all plant species were counted and recorded at each vegetative plot. By mid-September the counting was finished and 12 sampling points were randomly chosen in each watershed (and the north control in 1974) to determine the weight of each plant species. At each of the 12 sampling points a list was made of the plant species occurring on the three vegetative plots around that sampling point. For each plant species thus listed at a sampling point, enough stems (usually 10) were clipped at ground level within the surrounding timber inventory plot to allow accurate determination of oven-dry

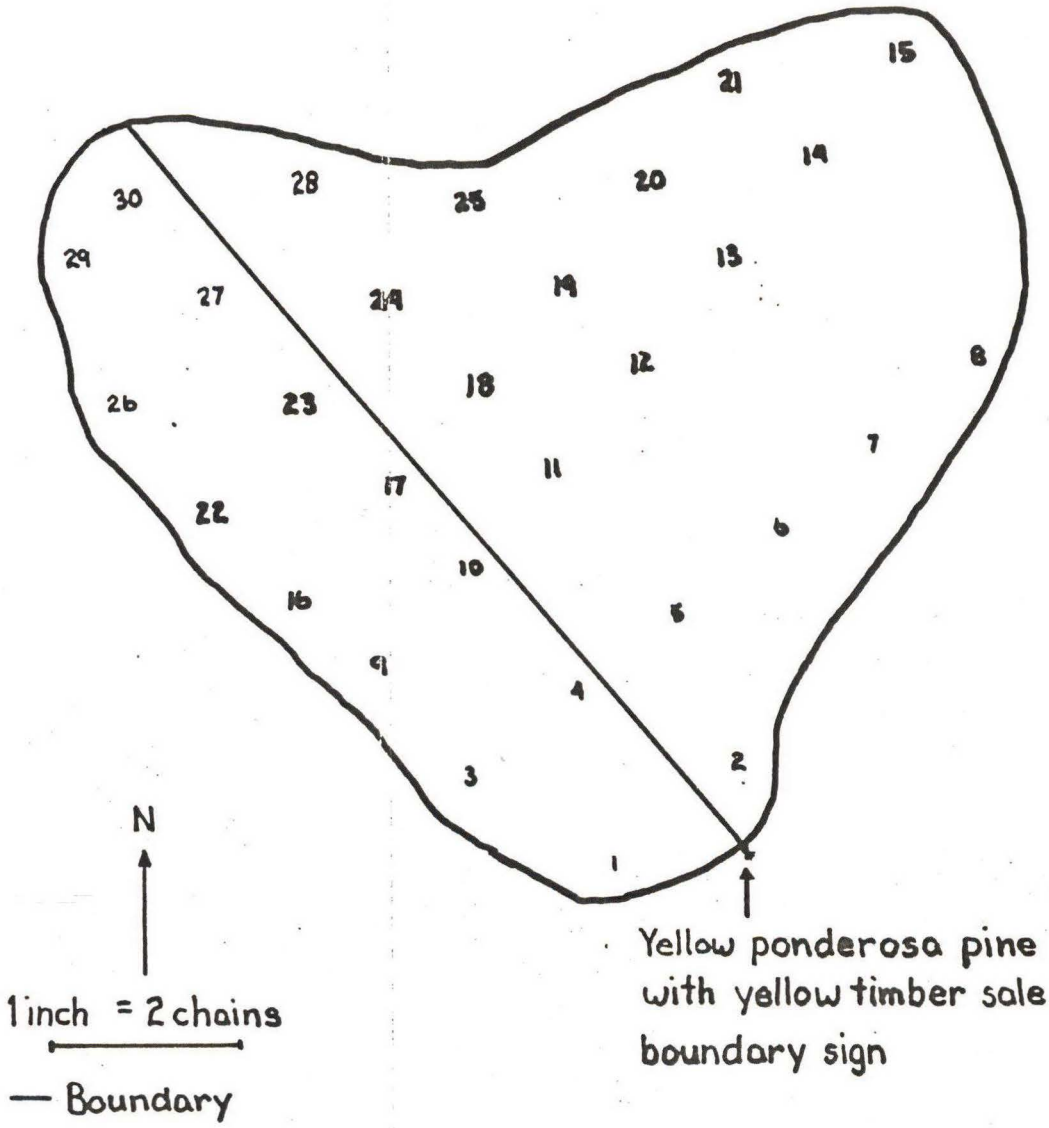

Figure 6. The location of sampling points on the north control area, Rattle Burn.

weight for that species on a Mettler balance (Types P-1200 and P-120 were used). Stems chosen to be clipped were compared with those counted on the vegetation plots to ensure similarity in size and conformity. A stem was defined as all vegetative parts arising from a single root crown. All weights reported are from material dried for 24 hours at 105°C. This method of vegetative measurement was designed to allow accurate determination of numbers of plants and weight by various observers having different amounts of experience without destructive sampling of the permanent plots.

Vegetative Analytical Techniques

The total herbage weight per watershed was analyzed with a two-way analysis of variance test, followed by the Student-Newman-Keuls multiple range test (Steel and Torrie, 1950). In the analysis of variance, an average weight of the three surrounding vegetative plots was used to represent each of the 30 sampling points within each watershed. Weight of the vegetative plots was obtained by multiplying the number of stems of each species by the average weight per stem of that species from stems clipped throughout the watershed.

The two variables tested in the analysis of variance

were passage of years and severity of burn. Null hypotheses were that no difference existed between samples from one year to the next or from one severity level to the other. Alternate hypotheses were that the means of some samples were greater than the means of other samples. All tests were made at the .05 level of confidence.

Numbers of stems were used to determine species composition. Species compositions were analyzed subjectively and by means of a standard similarity index in which "the number os species common to two areas is expressed as a percentage of the mean number of species per area, i.e. $\frac{2c}{a+b} \times 100$ where the two areas contain a and b species respectively and there are c species in common." (Greig-Smith, 1964, p. 137). Rather than comparing only the number of species on two areas, we used the number of stems of each species. Thus, the index gives not only a measure of similarity in terms of species present, but also in terms of the relative abundance of each species. Therefore, different stages of succession in the same community are better represented.

Measurement of Use by Herbivores

Plots and study areas for determining use by large herbivores could not be restricted to the confined areas of

the experimental watersheds because of the nature of the animal movements. Therefore, measurements of animal use were done on larger areas, somewhat uniformly burned, only a small part of which were sampled for vegetative data. For control areas, four areas were chosen around the outside of the burn, sampling all but the south side, in order to measure as many local differences in distribution of herbivores as possible. An attempt was made to place each set of control transects in an area as similar topographically as possible to the nearest burned sample area. Within sampled areas .0025 acre circular plots were systematically spaced on line-plot transects. Locations of pellet transect areas are in Figure 8. There were approximately 300 plots in each set of the moderately burned, severely burned, and control sample areas. The transect, rather than the plot, was used as the sample unit in order to reduce variability and reduce the number of zero readings. There were 15, 14, and 27 transects each in the moderately, severely, and unburned sample areas respectively. The sample statistic used was the average number of fecal deposits per plot, but this statistic has been converted to fecal deposits per acre of sampled area for ease of communication. Because of uncertainties connected with the statistical distribution of fecal deposits (Bowden, Anderson, and Medin, 1969) and the fact that sample

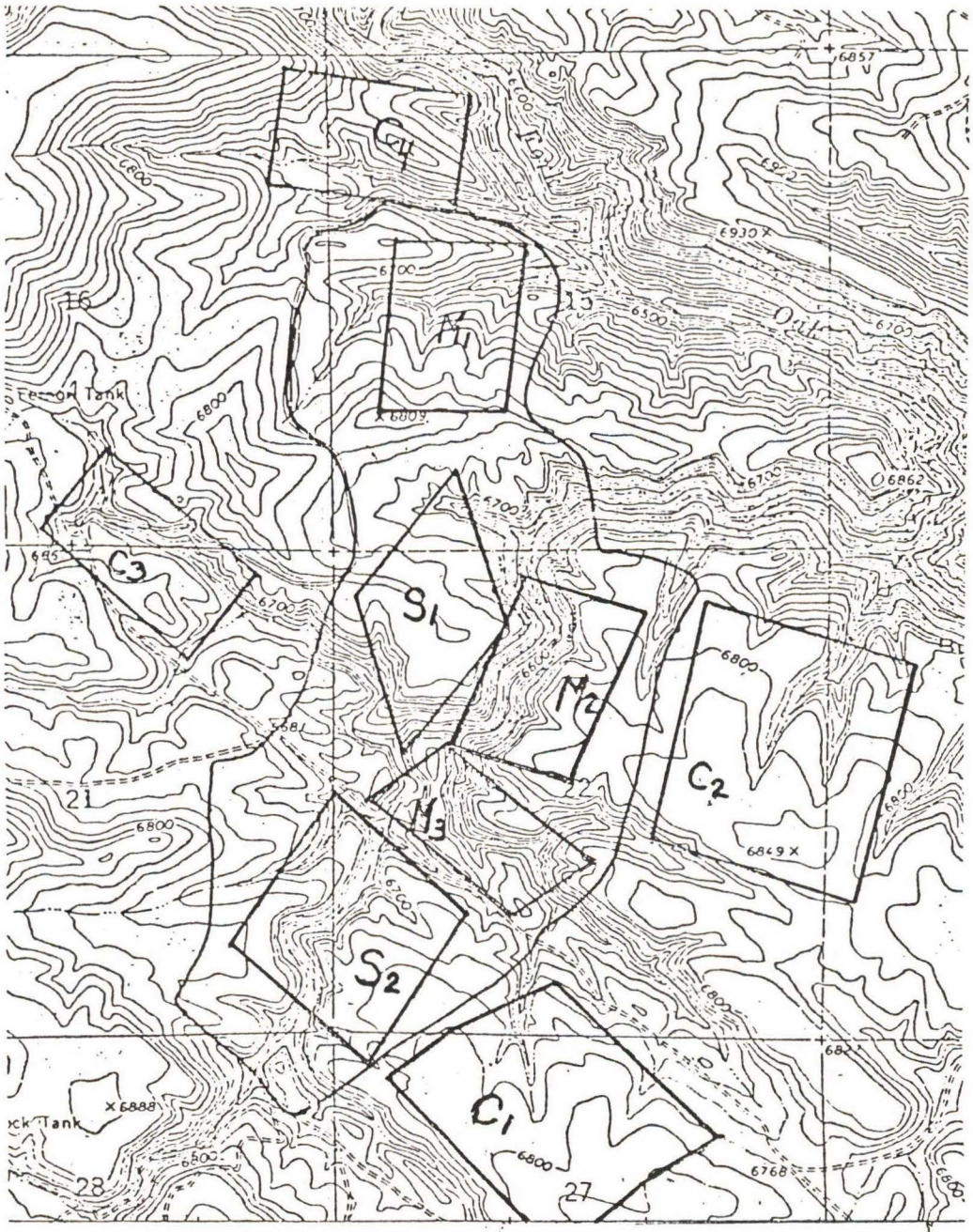

Figure 7. Map of Rattle Burn, showing areas sampled for fecal deposits of large herbivores.

intensities were not exactly the same, a Kruskal-Wallis Two-Way Analysis of Variance test was used on fecal deposit data. The Kruskal-Wallis test is independent of the underlying distribution, and is 95 percent efficient when compared with the parametric F test on normal data (Siegel, 1956). A .05 level of confidence was employed in the tests. As with vegetative data, testing was designed to differentiate between years and between severity of burn.

Fecal deposit transects were first established in July and August, 1972, and counted in late October of 1972, 1973, and 1974. Control transects were counted and cleared as they were established and again in October, 1972. An attempt was made to identify deposits of the summer on all transects in 1972. We hoped to reduce improper identification of the age of deposits by counting them on the control areas in early summer. Data from 1973 and 1974 represent full 12-month accumulation periods, of which only about 6 months should be considered as active accumulation periods for wild herbivores, and 5 months for cattle. These periods approximate the summer use period for the area.

Comparison of Herbivorous Use With Plant Species Composition

Graphical comparisons were made of total herbage in

each watershed and the degree of herbivorous use in each area sampled by fecal deposit transects. A similar comparison was made using the weight of plant species that are highly palatable for the particular animal being compared. Palatability ratings for deer were taken from Neff (1974). Those for elk were adapted from Murie (1951, pp. 196-202). Those for cattle were based on the author's knowledge of local conditions, with assistance in the herbaceous species from the U. S. Forest Service Range Environmental Handbook, Region 3, June, 1969 revision. Because comparisons were available for only two years on each of three areas regression analysis was deemed unnecessary.

RESULTS

Total Herbage Production

Mean herbage production in pounds per acre for each watershed and year are in Table 7. The analysis of variance showed no statistically significant difference in total herbage production in 1972 between the unburned watershed and those burned moderately and severely. There was, however, a difference between total herbage production on the watersheds in 1974 and on the burned watersheds from one year to the other.

Table 7. Mean herbage production in pounds per acre on each of three experimental watersheds in 1972 and 1974, Rattle Burn.

	Moderately burned	Severely burned	S. control	N. control
1972	452	582	474	---
1974	1275	1651	559	138

The Student-Newman-Keuls test showed that an increase in production occurred from 1972 to 1974 on both burned watersheds, but not on the south control. A "t" test showed no difference in total herbage production between the south and north controls in 1974. These results are similar to, but with larger increases than those reported by Pearson et al.(1972) and Kruse (1972) on basaltic soils.

Species Composition

Our highest similarity index of 54 was obtained by comparing the south control in 1972 with itself in 1974. An index of 54 appears, therefore, to be near-maximum for comparisons of numbers of stems per species in different years with different observers. This approximate maxima gives the high end of a comparative scale which descends to zero for areas completely dissimilar. Within the same geographical and altitudinal regime, the scale would descend to some number between 21 (our lowest index) and zero.

The similarity index pattern in Table 8 illustrates an area in which succession is proceeding fastest on the most severely disturbed area, and most slowly on the control areas. The north control and south control show enough difference that any possible differences between the moderately burned watershed and the control areas cannot be illustrated by the similarity analysis. It appears that the moderately burned watershed has reached a near-stabilization in understory species composition. Productivity, however, remains much greater than on the control areas. We can therefore conclude that the species lists for each watershed probably represent stages of succession after fire of different intensities. Species of plants that appear to

Table 8. Differences in plant communities between two burned and two unburned watersheds in the Rattle Burn, 1972 and 1974.

Comparison	Similarity index [1]
South control 1974- same area 1974	54
Moderately burned 1972 - same area 1974	53
North control 1974 - moderately burned 1974	53
South control 1974 - north control 1974	45
Moderately burned 1974 - south control 1974	44
Moderately burned 1972 - south control 1972	35
Moderately burned 1974 - severely burned 1974	35
Severely burned 1974 - south control 1974	32
Severely burned 1972 - same area 1974	27
Severely burned 1972 - south control 1972	24
Moderately burned 1972 - severely burned 1972	21

1) Derived from results of ninety 9.6 square foot plots on each watershed, using $\frac{2c}{a+b}$ x 100, where a = number of stems of all species on plots in area a; b= number of stems of all species on plots in area b; c= sum of smallest number of stems of those species common to both areas. A higher index shows greater similarity.

be increasing or decreasing in this situation (Tables 9-12) should represent species that are adapted to various stages of succession or disturbance. From this information we should be able to predict approximately what the nature of the herbaceous understory will be if an early spring fire burns a similar area, with similar subsequent rainfall patterns. Our results should also show which plants have likelihood of germination and success after fire. Plant succession in the Rattle Burn area seems to return to the untreated state more rapidly than reported by Reynolds (1962) for a different area in northern Arizona.

Table 9. Plants present on plots in the severely burned watershed that were absent on plots in the nearest unburned watershed.[1]

Agropyron spp. (seeded)	*Portulaca oleracea*
Cerastium vulgatum	*Senecio bigelovii*
Melilotus alba (seeded)	*S. spartioides*
M. officinalis (seeded)	

1) To be considered absent, a plant had to be absent during both 1972 and 1974. To be listed as present on the burned area, a plant had to be counted 10 times on plots. This was done to eliminate aberrations caused by failure to sample infrequent species.

Table 10. Plants absent on plots in the severely burned watershed that were present in the nearest unburned area.[1]

Fragaria spp.	*Muhlenbergia montana*
Geranium spp.	*Pseudocymopteris montana*
Malaxis soulei	*Thalictrum fendleri*
Muhlenbergia virescens[2]	

1) To be considered absent, a plant had to be absent during both 1972 and 1974. To be listed as present on the unburned watershed, a plant had to be counted 10 times on plots. This was done to eliminate aberrations caused by failure to sample infrequent species.
2) This species was not present on plots in either area. It is listed here because of its ecological significance and because a special search was conducted to locate individuals of this species in both areas.

Table 11. Plants most abundant on the severely burned watershed and least abundant on the unburned watersheds, Rattle Burn, 1972 and 1974.

Amaranthus retroflexus[1]	Muhlenbergia minutissima[2]
Arenaria lanuginosa[1]	Polygonum sawachense
Ceanothus fendleri	Portulaca oleracea
Gayophytum nuttallii	Pteridium aquilinum[3]
Lotus spp.	Rumex acetosella
Melilotus alba (seeded)	Senecio spp.
Melilotus officinalis (seeded)	

1) These plants were more abundant on the unburned areas in 1972.
2) More abundant on south control than on moderately burned watershed. It occurred on roads in the south control.
3) More abundant on south control than on moderately burned watershed. Rare on north control.

Table 12. Plants most abundant on the moderately burned watershed, Rattle Burn, 1972 and 1974.

Fragaria spp.	Senecio bigelovii
Linanthastrum nuttallii	Senecio multilobatus
Lupinus hillii	Senecio neomexicanus
Monarda menthaefolia	Senecio wootonii
Plantago spp.	Taraxacum spp.
Poa spp.	Tragopogon dubius
Robinia neomexicana[1]	Verbascum thapsus
Rosa arizonica	Vicia americana
Senecio actinella	

1) There may not have been a source for reproduction in the severely burned area.

Differences in Use by Herbivores

The only differences in use of areas by herbivores that proved to be statistically significant were: 1) Deer use between the three areas in 1972 and 1974 (Figure 8 and Table 13). 2) Deer use on the moderately burned and control areas between the three years. 3) Cattle use between the three areas in 1974 (Figure 9, Table 13). 4) Cattle use on the severely burned area between the three years. Elk data could not be tested except in 1974, when no difference existed (Figure 10, Table 13). One year that contributed to the difference in deer depositions was 1972, with high readings in the control and moderately burned areas. Over half of the pellets on the control area in 1972 were counted during the October reading so it appears that there was no significant error from counting groups deposited in previous years. The test was still significant when only the October count was used. A low number of deer pellet groups was counted in 1974 in the control areas. That difference probably also contributed to the statistical significance across years in the control areas. Use by deer of the severely burned areas may have been higher were it not for near-complete removal of the numerous Ceanothus fendleri seedlings by grazing or browsing in 1972. The significant difference between years for cattle depositions in the severely burned areas was entirely due to a large

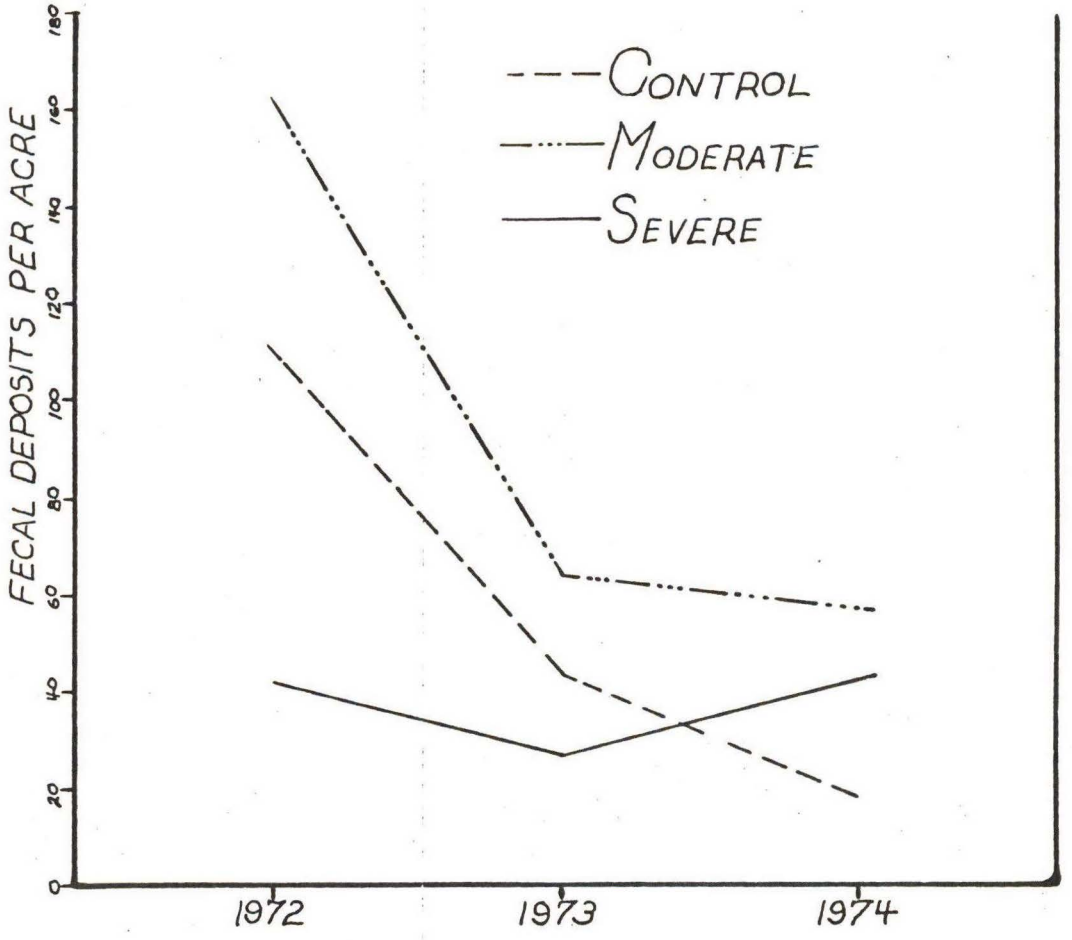

Figure 8. Use by deer of unburned, moderately burned, and severely burned areas, Rattle Burn, 1972-1974.

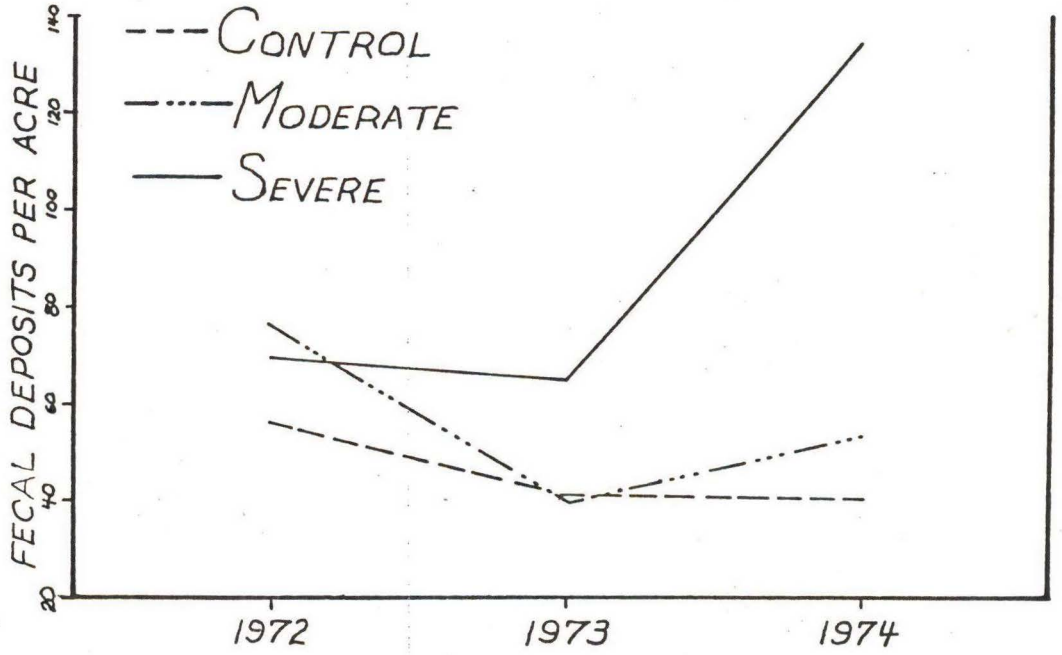

Figure 9. Use by cattle of unburned, moderately burned, and severely burned areas, Rattle Burn, 1972-1974.

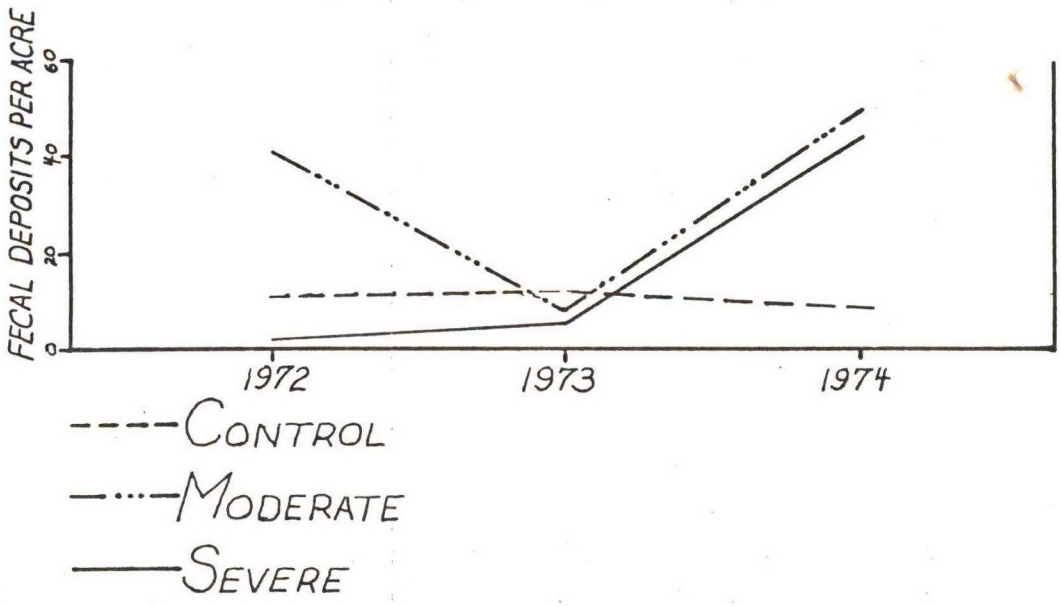

Figure 10. Use by elk of unburned, moderately burned, and severely burned areas, Rattle Burn, 1972-1974.

Table 13. Use by large herbivores of an unburned area and areas burned moderately and severely, Rattle Burn, 1972-1974.

Area	Fecal depositions per acre								
	Deer[1]			Elk[1]			Cattle[1]		
	1972	1973	1974	1972	1973	1974	1972	1973	1974
Unburned	110	44	19	12	12	9	58	41	41
Moderately burned	164	65	58	41	8	50	76	40	53
Severely burned	42	28	43	3	6	44	70	65	134

1) Pellet plots were established in June-August, 1972, and cleared again in October, 1972. Thereafter, the accumulation period was 12 months. However, the area is primarily summer range, with winter use probably varying according to snowfall.

increase in 1974. This may be attributable to the openness of the severely burned areas, the increased herbage there, and the increase in cattle concentration in part of the area caused by water distribution problems in other parts of the Barney Pasture allotment. The number of fecal deposits counted in the burned areas, particularly in the severely burned area in 1973 and to a lesser extent in 1972 may be artificially low because of on-site disturbance and destruction of plots by machinery.

Relationship of Fecal Counts To Herbage Production

Deer, elk, and cattle use are plotted with total herbage production on each watershed for 1972 and 1974 in Figures 11-16. In an effort to improve the relationship of the production and use curves, only the plants that are highly palatable in spring, summer, or fall were used in Figures 17-22. Only the curves comparing elk and cattle use with herbage production in 1974 failed to show a stronger relationship after this manipulation. Examination of the improvement in fit thus effected shows that the improvement was greatest where the most accurate palatability ratings were available (for deer). Information was extensive for elk palatability, but in a form requiring more extrapolation. Information on herbaceous palatability

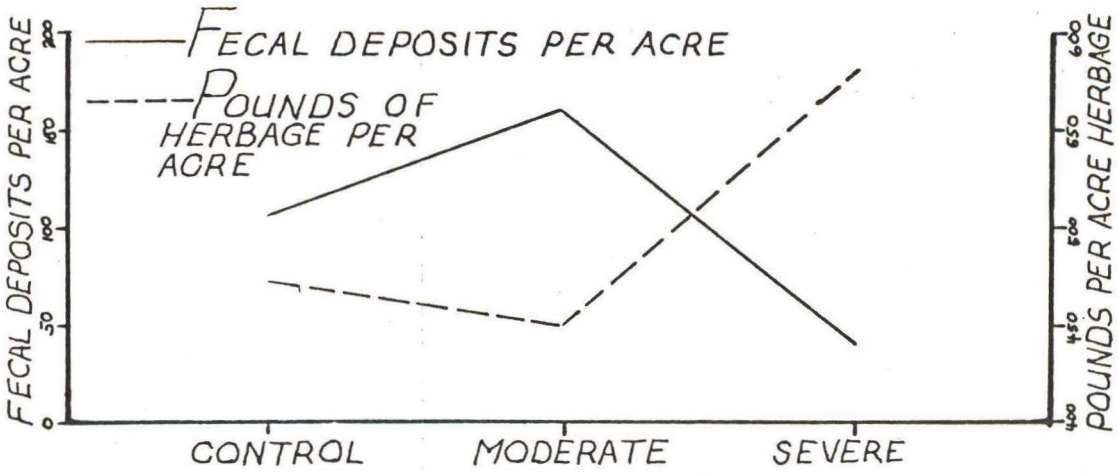

Figure 11. Use by deer compared with total herbage production on unburned, moderately burned, and severely burned areas, Rattle Burn, 1972.

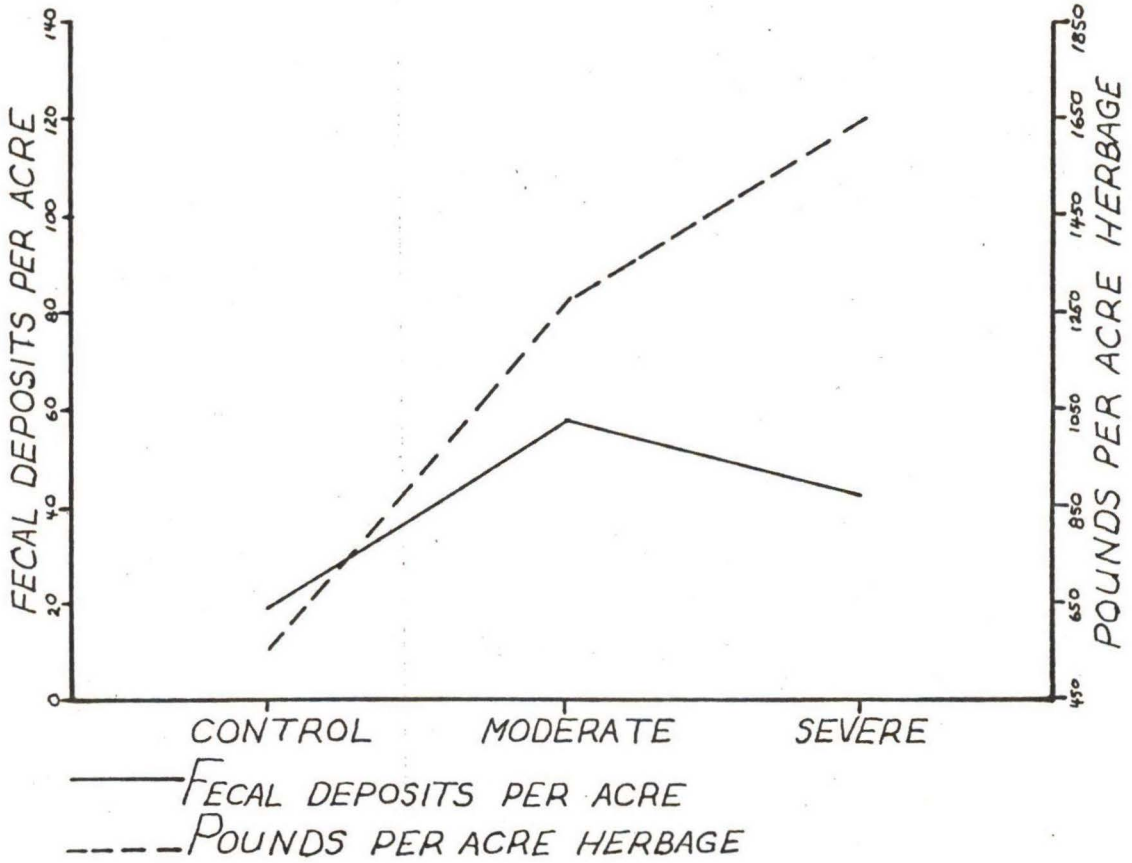

Figure 12. Use by deer compared with total herbage production on unburned, moderately burned, and severely burned areas, Rattle Burn, 1974.

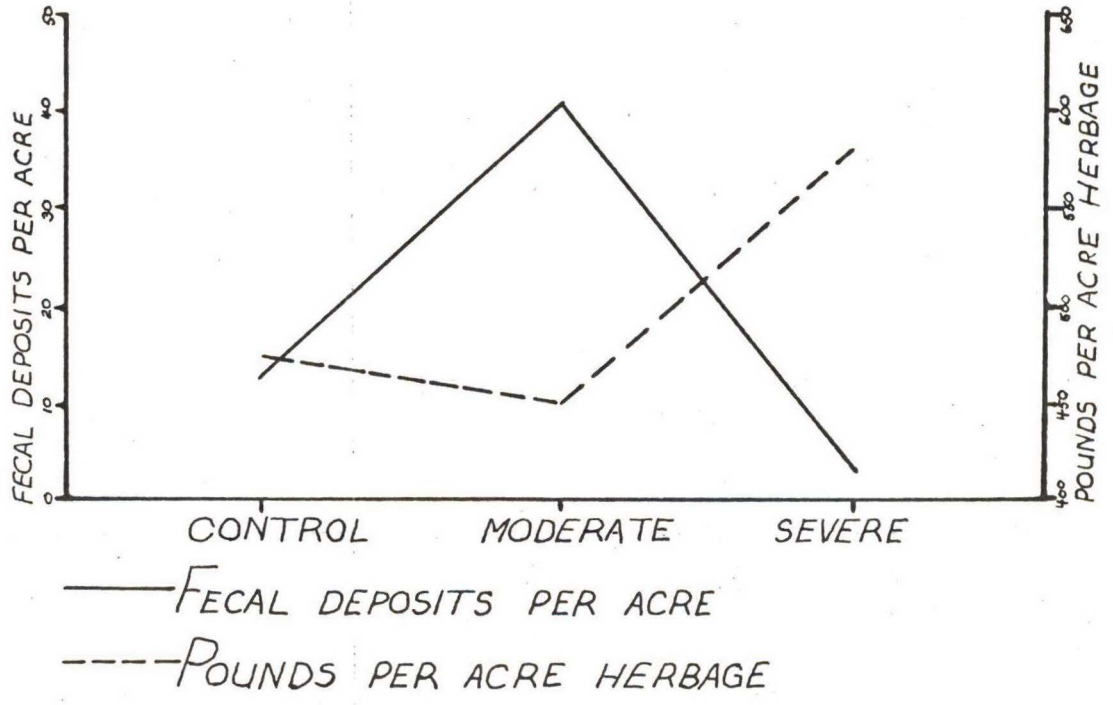

Figure 13. Use by elk compared with total herbage production on unburned, moderately burned, and severely burned areas, Rattle Burn, 1972.

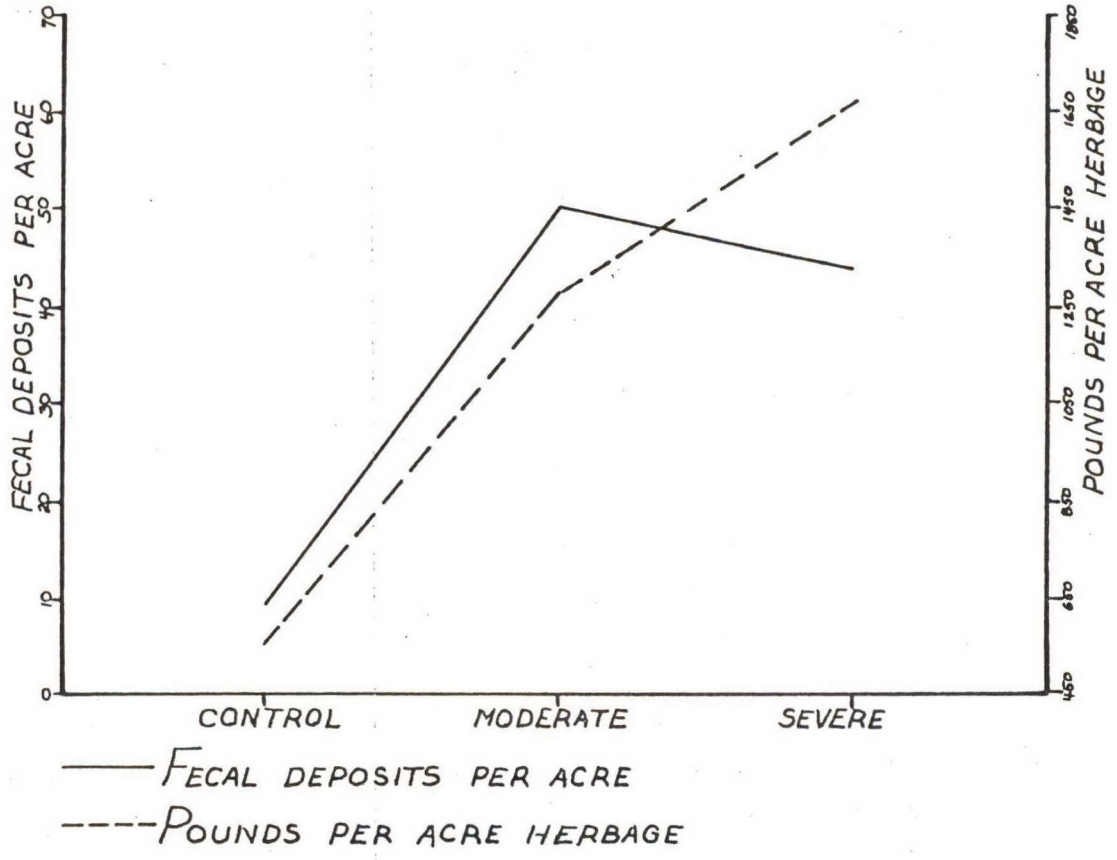

Figure 14. Use by elk compared with total herbage production on unburned, moderately burned, and severely burned areas, Rattle Burn, 1974.

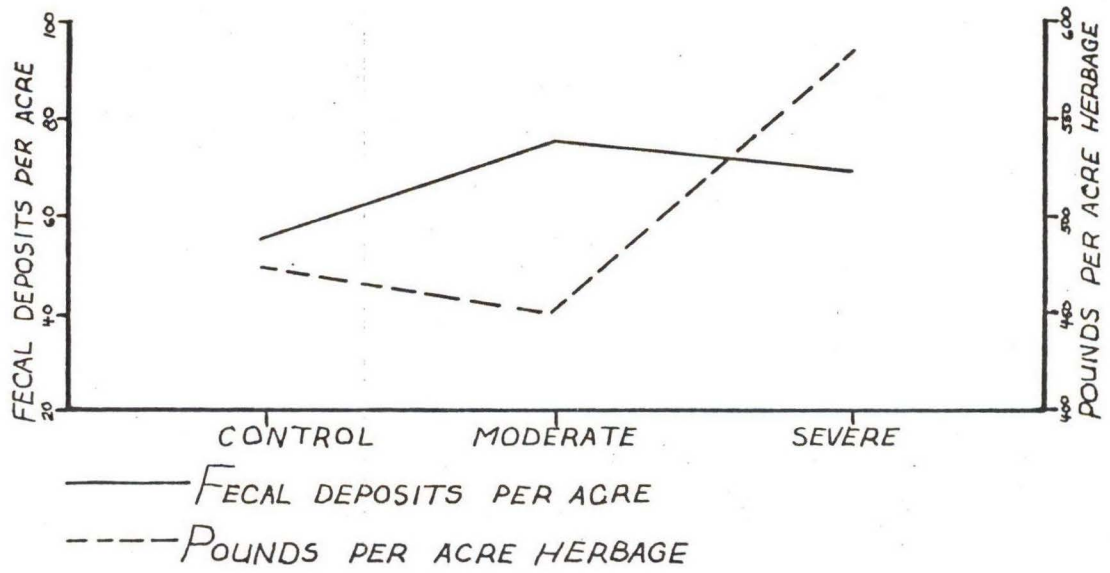

Figure 15. Use by cattle compared with total herbage production on unburned, moderately burned, and severely burned areas, Rattle Burn, 1972.

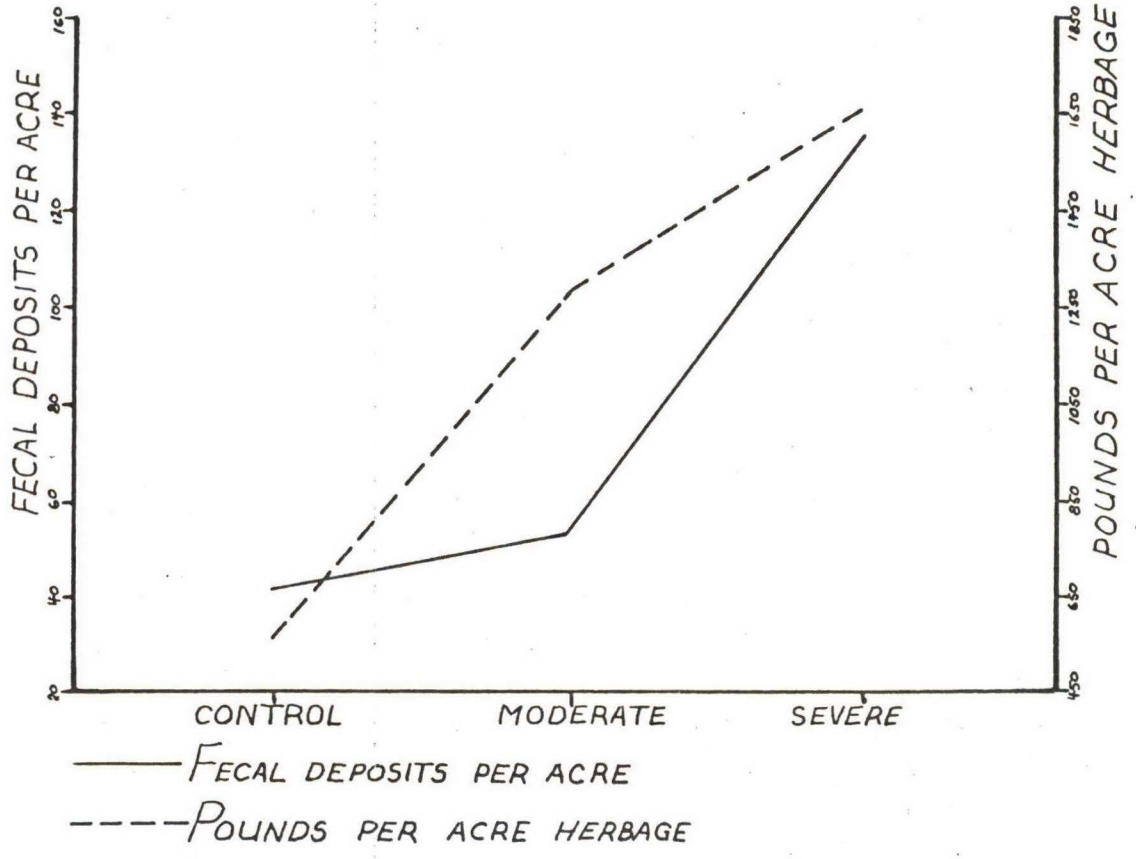

Figure 16. Use by cattle compared with total herbage production on unburned, moderately burned, and severely burned areas, Rattle Burn, 1974.

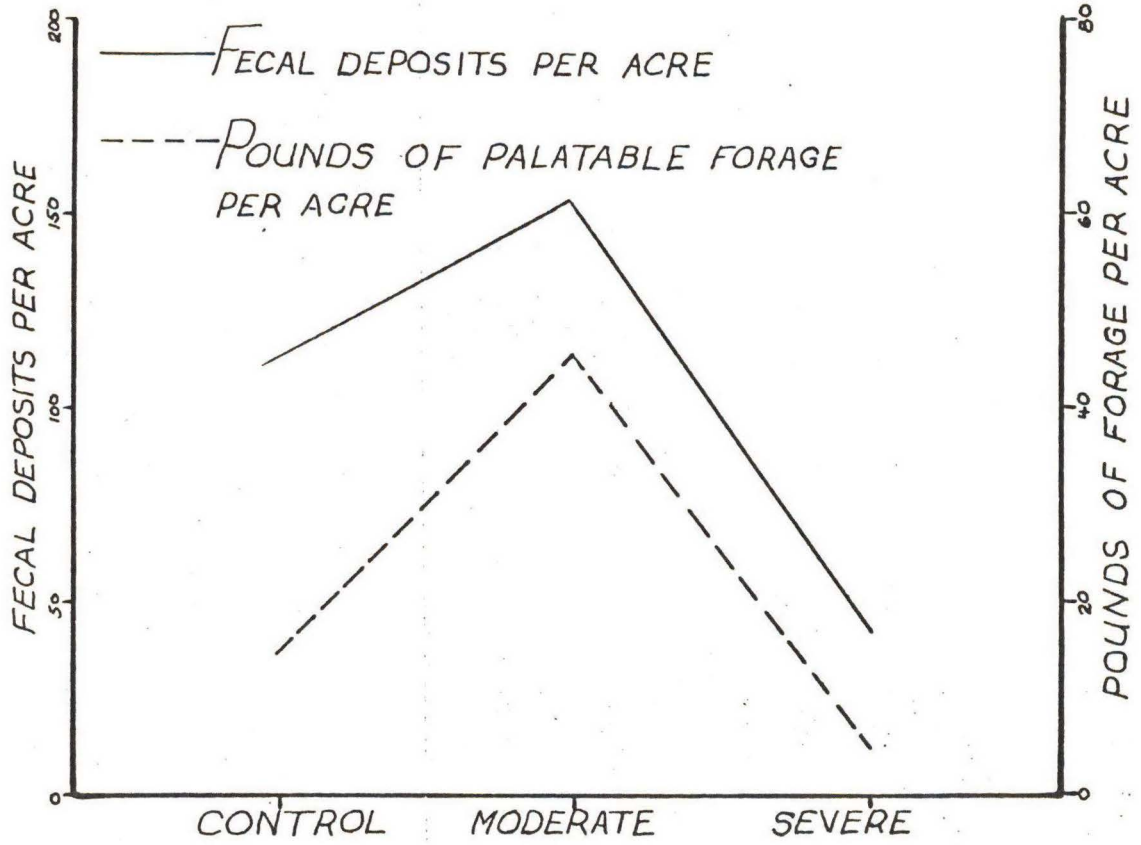

Figure 17. Use by deer compared with production of highly palatable plants on unburned, moderately burned, and severely burned areas, Rattle Burn, 1972.

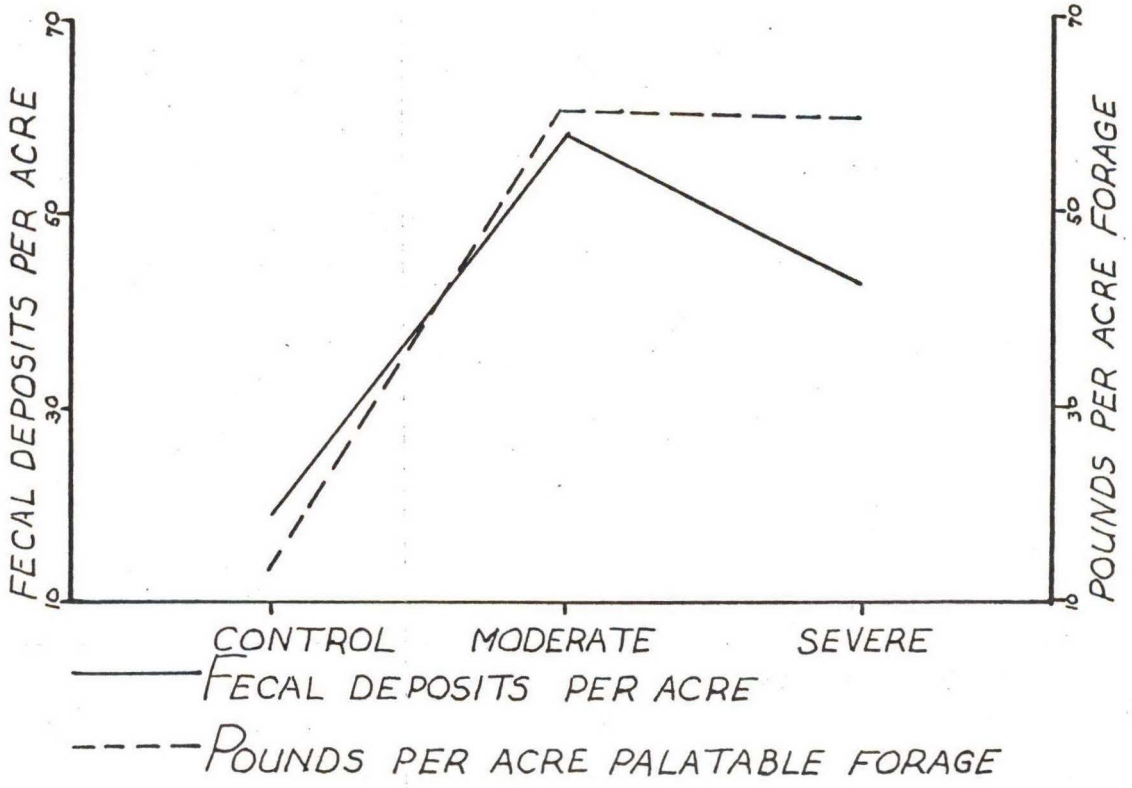

Figure 18. Use by deer compared with production of highly palatable plants on unburned, moderately burned, and severely burned areas, Rattle Burn, 1974.

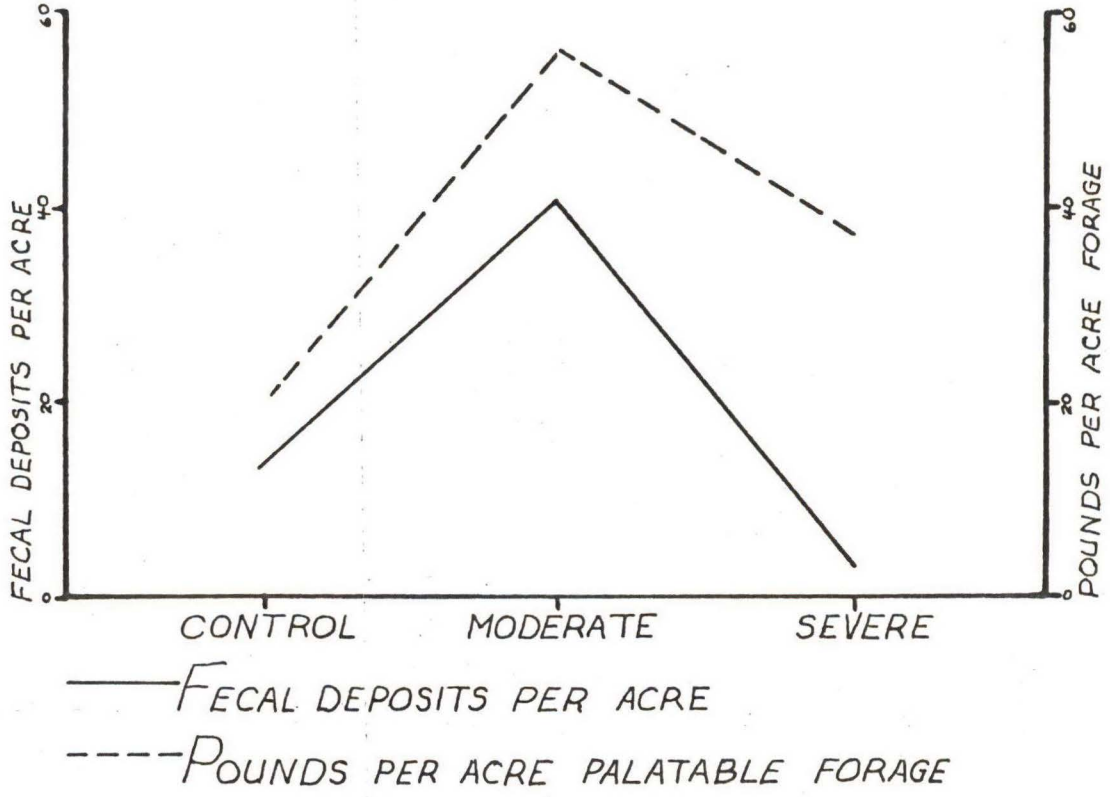

Figure 19. Use by elk compared with production of highly palatable plants on unburned, moderately burned, and severely burned areas, Rattle Burn, 1972.

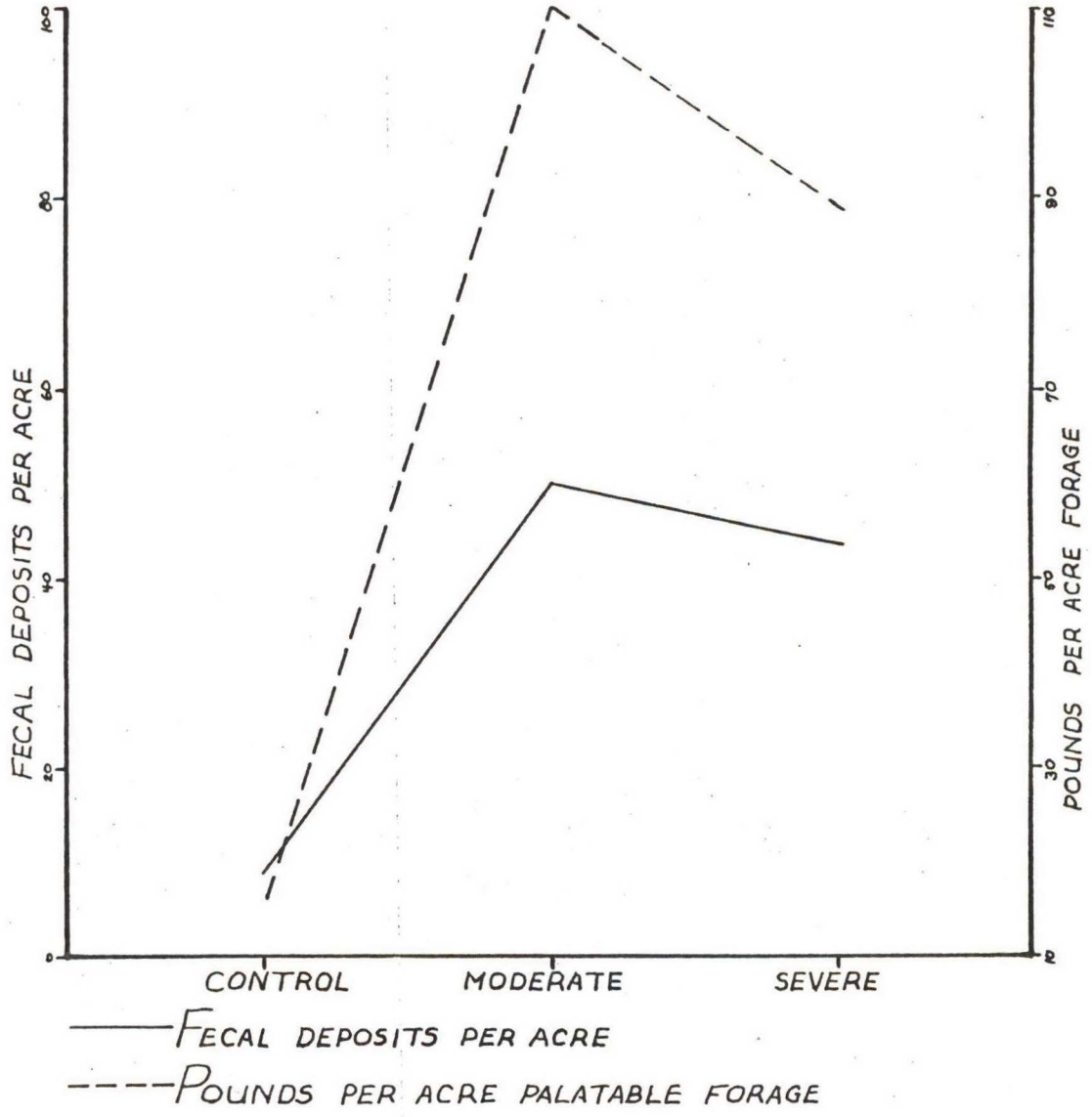

Figure 20. Use by elk compared with production of highly palatable plants on unburned, moderately burned, and severely burned areas, Rattle Burn, 1974.

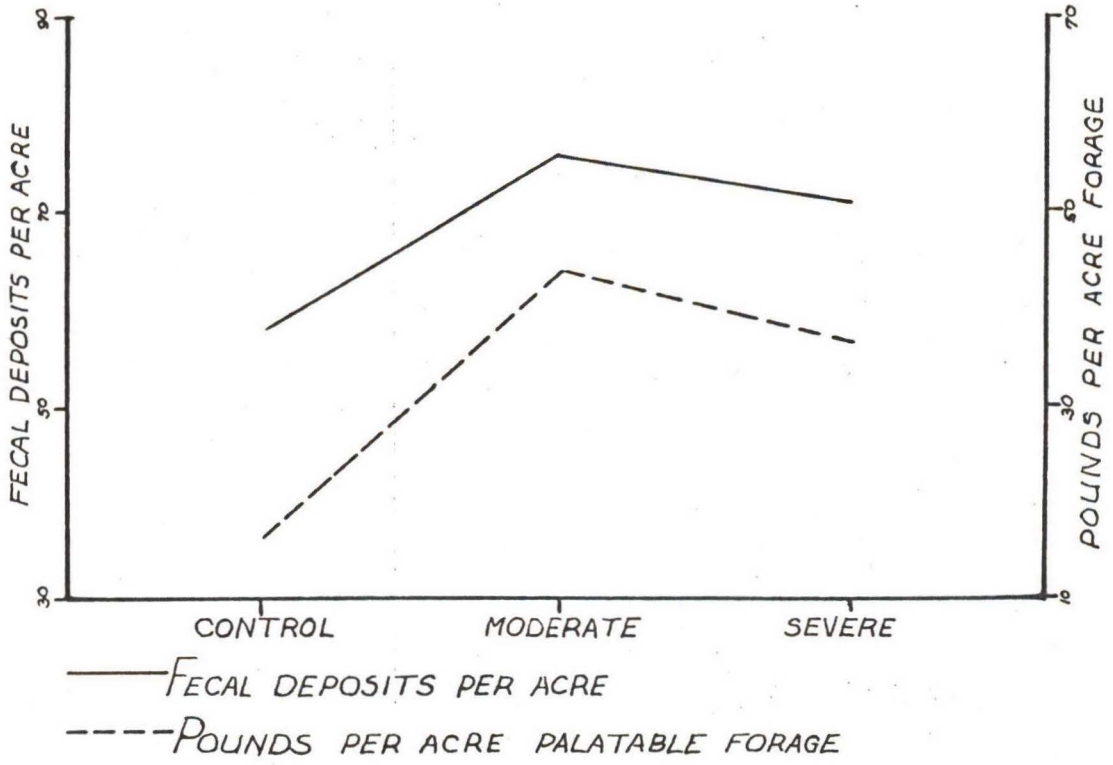

Figure 21. Use by cattle compared with production of highly palatable plants on unburned, moderately burned, and severely burned areas, Rattle Burn, 1972.

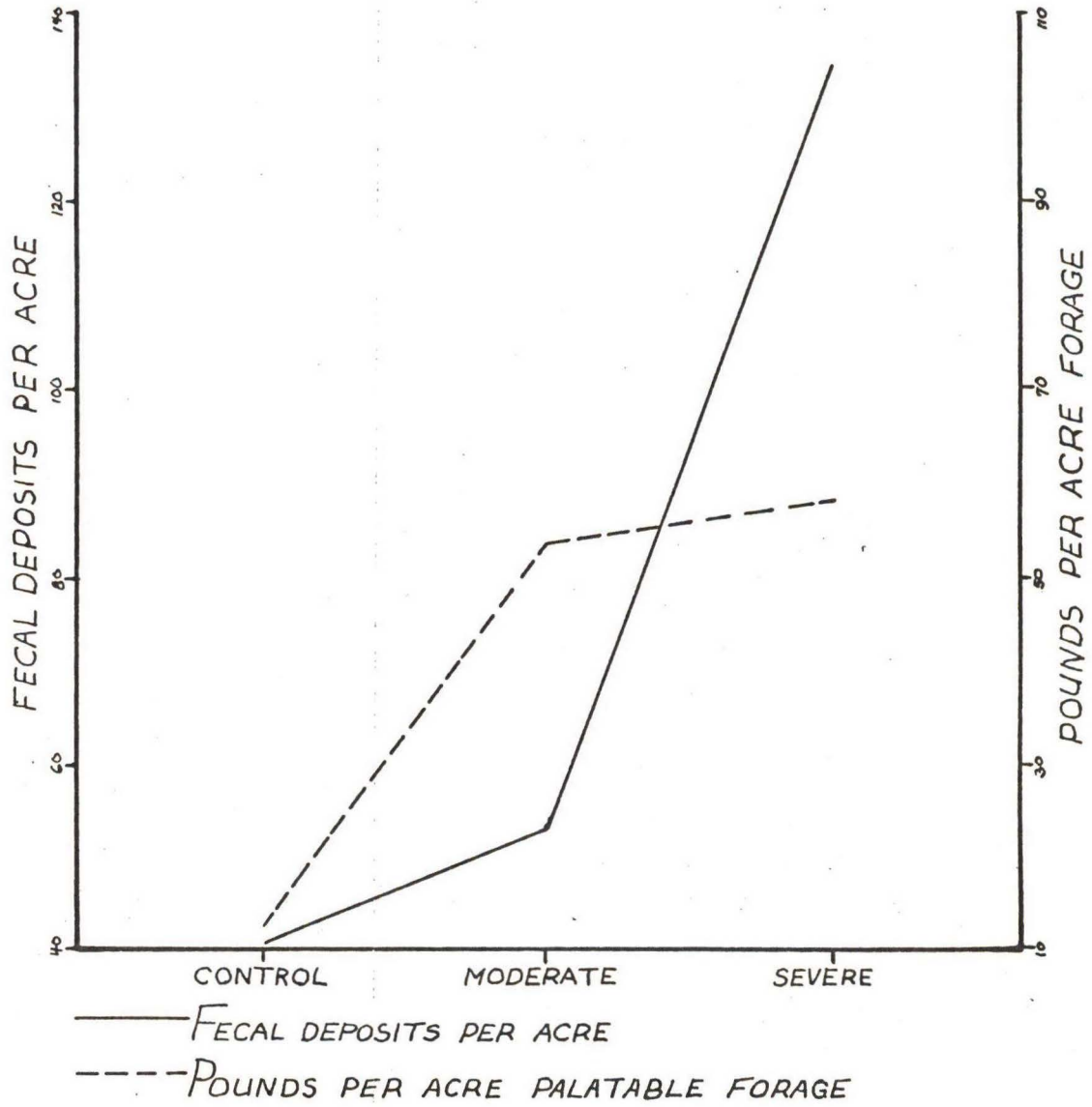

Figure 22. Use by cattle compared with production of highly palatable plants on unburned, moderately burned, and severely burned areas, Rattle Burn, 1974.

for cattle was inadequate and cattle numbers were also influenced by management practices. It is to be expected then, that efforts to compare cattle use to herbage production by palatability classes would have limited success.

To summarize, use by elk and cattle either could not be tested or differences could be explained by factors unrelated to the fire. Use by deer of the severely burned area exceeded the level of the control after two years. Use by deer of the moderately burned area exceeded that of the control the year of the fire. The pattern of use by deer in different years and on different areas appears to be related to the production of highly palatable plants.

CONCLUSIONS

Conclusions from this study are:

1) The nature of plant species in this area is more closely related to use by deer than is total herbage production.
2) Destruction of cover for deer (in this setting of a long-oval 748 acres with interspersed areas burned at lesser intensity) appears to have had no appreciable deleterious effect once palatable plant species appeared. Use on the severely burned area exceeded the level of the control after two years. Use on the moderately burned area exceeded that on the control the year of the fire. There was no observable effect on elk use of the burned or unburned areas.
3) To manage areas for deer, one should encourage food species listed as highly palatable in research publications such as that by Neff (1974).
4) Fire-caused damages and benefits revealed by this study were:
    a) Immediate and large-scale benefit to deer in moderately burned areas.
    b) Negligible or minor damage to deer and elk during the first two years after a severe crown fire similar to the Rattle Fire.
    c) Third year benefit to deer after a severe crown fire

like the Rattle Fire. This benefit may be expected to continue as plant succession takes place at least through the stage represented by the moderately burned area three years after the fire.

RECOMMENDATIONS

As a result of this study, the authors recommend that:

1) References to damage by wildfire to the habitat of large herbivores on sites similar to that reported herein not be made in fire damage reports and public announcements during and following large, early spring wildfires unless the size and intensity of the fire considerably exceeds that of the Rattle Fire of May, 1972.

2) The amount of successional information presented herein should be expanded and used by managers in prescribing the use of fire in similar plant communities throughout the ponderosa pine forests of northern Arizona. Further research would be helpful in refining the successional knowledge, and in expanding it to other habitat-types.

3) One more year's data should be gathered in the present study to firmly establish the herbivorous use and successional trends in the absence of outside disturbance. The study should then be reactivated at 10-year intervals until the area is stable in successional trend.

4) It was obvious to the authors during the course of the study that the greater degree of disturbance to the soil and understory plant resources occurred as a result of the salvage logging and cleanup operations with heavy equipment, rather than as a result of the

fire. We would therefore recommend that salvage logging contracts be revised and administered in a manner that will prevent unnecessary soil disturbance, particularly during the second and subsequent years after the fire. We recommend that soil disturbance at all times be kept to a minimum except when necessary for pine regeneration by seed or to destroy a dense hydrophobic layer, the nature of which is shown on the site to be such that it would persist for several years and prevent plant growth.

5) Further research should be conducted into herbaceous palatability for deer in plant communities much different from the one studied by Neff (1974). Similar research is needed in several plant associations for elk and domestic stock.

APPENDIX

Plants identified in and near Rattle Burn, southwest of Flagstaff, Arizona.

Achillea lanulosa
Agropyron spp.
Agoseris arizonica
Agrostis scabra
Amaranthus retroflexus
Androsace septentrionalis
Anemone tuberosa
Antennaria parvifolia
Anthericum torreyi
Aquilegia chrysantha
Arenaria lanuginosa saxosa
Asclepias speciosa
A. subverticillata
A. tuberosa
Astragalus humistratus
Atriplex rosea
Berberis repens
Blepharoneuron tricolepis
Bromus spp.
Carex spp.
Castilleja austromontana
Ceanothus fendleri
Cerastium vulgatum
Chenopodium album
Chenopodium graveolens
Chrysopsis villosa
Cirsium pulchellum
Cleome serrulata
Conyza canadensis
Cryptantha jamesii
Cyperis fendlerianus
Dactylis glomerata
Delphinium geraniifolium
Draba asprella
Epilobium angustifolium
E. paniculatum
Eragrostis spp.
Erigeron concinnus
E. divergens
E. flagellaris
E. utahensis
E. pharnaceoides
E. spp.
Erysimum capitum
Euphorbia fendleri
E. lurida
Fragaria spp.
Gayophytum nuttallii
Geranium parryi
G. richardsonii
Gilia agglegata
Helianthella quinquenervis
Hieracium fendleri
Houstonia wrightii
Hymenopappus mexicanus
Iris missouriensis
Kelloggia galioides
Lappula ledowski
Lathyrus leucanthus laetivirens
Lathyrus spp.
Lepidium densiflorum
L. montanum
Linanthastrum nuttallii
Lithospermum multiflorum
Lotus utahensis
L. wrightii
Lupinus hillii
Malaxis soulei
Medicago lupulina
Melilotus alba
M. officinalis
Mimulus spp.
Monarda menthaefolia
Muhlenbergia montana
M. virescens
M. annual
Nicotiana attenuata
Oenothera caespitosa
O. flava
O. hookeri
O. laciniata
O. procera
Oxybaphus linearis
Penstemon virgatus
Panicum bulbosum
Petalostemum candidum

Phacelia magellanica
Phaseolus angustissimus
Phleum pratense
P. spp.
Pinus ponderosa
Plantago Argyraea
Poa compressa
P. fendleriana
P. pratensis
P. spp.
Polygonum sawachense
Portulaca oleracea
Potentilla crinita
P. hippiana
Prunella vulgaris
Pseudocymopterus montanus
Pteridium aquilinum
Quercus gambelii
Ranunculus cardiophyllus
R. inamoenus
Robinia neomexicana
Rosa arizonica
Rumex acetosella
Senecio actinella
S. bigelovii
S. multilobatus
S. neomexicanus
S. wootonii
S. spp.
Silene scouleri
Sisymbrium altissimum
S. linearifolium
Sitanion longifolium
Solidago missouriensis
S. sparsiflora
Stipa pringlei
Taraxacum spp.
Thalictrum fendleri
Thermopsis pinetorum
Tragopogon dubius
Trifolium repens
Valeriana edulis
Verbascum thapsus
Verbena bracteata
V. goodingii
Vicia americana

LITERATURE CITED

Ahlgren, I. F., and C. E. Ahlgren. 1960. Ecological effects of forest fires. Bot. Rev. 26:483-533.

Biswell, H. H. 1967. Forest fire in perspective. Proc. Tall Timbers Fire Ecology Conf. 2: 43-63

Bowden, D. C., A. E. Anderson, and D. E. Medin. 1969. Frequency distributions of mule deer fecal group counts. J. Wildl. Mgmt. 33: 895-905.

Clary, W. P., and P. F. Ffolliott. 1966. Differences in herbage-timber relationships between thinned and unthinned ponderosa pine stands. U.S. Forest Service, Rocky Mountain Forest and Range Experiment Station, RM-74, 4 pp.

Clary, W. P., P. F. Ffolliott, and D. A. Jameson. 1968. Relationship of different forest floor layers to herbage production. U. S. Forest Service, Rocky Mountain Forest and Range Experiment Station, RM-123, 3 pp.

Clary, W. P. and F.R. Larson. 1971. Elk and deer use are related to food sources in Arizona ponderosa pine. U. S. Forest Service, Rocky Mountain Forest and Range Experiment Station, RM-202, 4pp.

Davis, J. R., P. F. Ffolliott, and W. P. Clary. 1968. A fire prescription for consuming ponderosa pine duff. U. S. Forest Service, Rocky Mountain Forest and Range Experiment Station, RM-115, 4 pp.

De Bano, L. F., and R. M. Rice. 1973. Water repellent soils, their implication in forestry. J. For. 71: 220-223.

Fuller, W. H., S. Shannon, and P. S. Burgess. 1955. Effect of burning on certain forest soils of northern Arizona. Forest Sci. 1: 44-50.

Greig-Smith, P. 1964. Quantitative plant ecology. Butterworths, London. 256 pp.

Hanks, J. P. and E. L. Fitzhugh. 1975. Preliminary report, habitat typing of ponderosa pine in northern Arizona. Unpublished report, U. S. Forest Service, Region 3, Albuquerque.

Herman, F. R. 1954. A guide for marking fire-damaged ponderosa pine in the Southwest. U. S. Forest Service, Rocky Mountain Forest and Range Experiment Station, RM-13. 4 pp.

Hooven, E. F. 1973. A wildlife brief for clearcut logging of Douglas-fir. J. For. 71:211-214.

Komarek, E. V. 1967. Fire and the ecology of man. Proc. Tall Timbers Fire Ecology Conf. 6:143-170.

Kruse, W. H. 1972. Effects of wildfire on elk and deer use of a ponderosa pine forest. U. S. Forest Service, Rocky Mountain Forest and Range Experiment Station, RM-226. 4 pp.

Lay, D. W. 1956. Effects of prescribed burning on forage and mast production in southern pine forest. J. For. 54: 582-585.

McConnell, B. R. and J. G. Smith. 1970. Response of understory vegetation to ponderosa pine thinning in eastern Washington. J. Range Mgmt. 23: 208-212.

Murie, O. J. 1951. The elk of North America. The Stackpole Company, Harrisburg, and the Wildlife Management Institute, Washington. 376 pp.

Neff, D. J. 1974. Forage preferences of trained mule deer on the Beaver Creek watersheds. Special Report No. 4, Arizona Game and Fish Department. 61 pp.

Patton, D. R. 1969. Deer and elk use of a ponderosa pine forest in Arizona before and after timber harvest. U. S. Forest Service, Rocky Mountain Forest and Range Experiment Station, RM-139. 7 pp.

Pearson, H. A., J. R. Davis, and G. H. Schubert. 1972. Effects of wildfire on timber and forage production in Arizona. J. Range Mgmt. 25: 250-253.

Quick, C. R. 1959. Ceanothus seeds and seedlings on burns. Madrono. 15:79-81.

Reynolds, H. G. 1962. Effects of logging on understory vegetation in ponderosa pine forest in Arizona. U. S. Forest Service, Rocky Mountain Forest and Range Experiment Station, RM-208. 7 pp.

Reynolds, H. G. 1966. Use of a ponderosa pine forest in Arizona by deer, elk, and cattle. U. S. Forest Service, Rocky Mountain Forest and Range Experiment Station, RM-63. 7 pp.

Schinzel, R. and R. T. Meurisse. 1972. Soils report, Rattle Burn area, Flagstaff ranger district, Coconino National Forest. Unpublished report, U. S. Forest Service, Region 3, Albuquerque. 16 pp.

Siegel, S. 1956. Nonparametric statistics for the behavioral sciences. McGraw-Hill, New York. 312 pp.

Steel, R. G. D. and J. H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill, New York. xvi + 481 pp.

Sweeney, J. R. 1967. Ecology of some "fire type" vegetations in northern California. Proc. Tall Timbers Fire Ecology Conf. 7: 111-126.

Tarrant, R. F. 1956. Effect of slash burning on some physical soil properties. Forest Sci. 2:18-22.

Weaver, H. 1958. Effects of burning on range and forage values in the ponderosa pine forest. Proc. Soc. Am. Foresters. 1958: 212-215.

_____ 1967. Fire and its relationship to ponderosa pine. Proc. Tall Timbers Fire Ecology Conf. 7: 127-150.

Williams, J. T. 1962. Dormancy of Chenopodium album L. A. Appl. Biol. 50:352.

Zwolinski, M. J. 1966. Changes in water infiltration capacities following burning of a ponderosa pine forest floor. Ph.D. dissertation, U. of Ariz., Tucson. xv + 192 pp.